NECESSITY for DEVELOPMENT of STANDARDS for USE of SELECTED NONMEDICAL ELECTRONIC PRODUCTS

BRH/DEP 70-30

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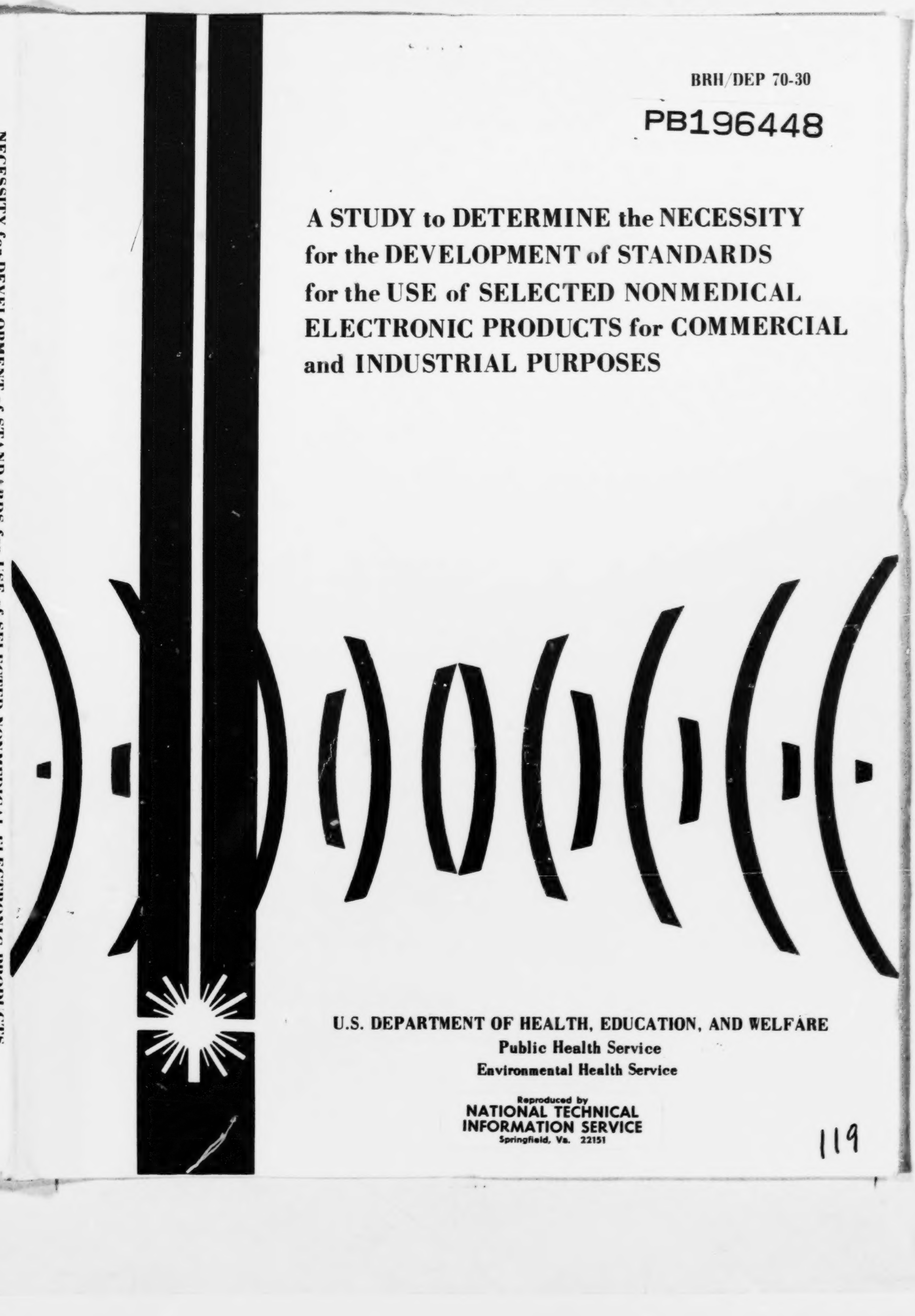
A STUDY to DETERMINE the NECESSITY for the DEVELOPMENT of STANDARDS for the USE of SELECTED NONMEDICAL ELECTRONIC PRODUCTS for COMMERCIAL and INDUSTRIAL PURPOSES



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A STUDY to DETERMINE the NECESSITY for the DEVELOPMENT of STANDARDS for the USE of SELECTED NONMEDICAL ELECTRONIC PRODUCTS for COMMERCIAL and INDUSTRIAL PURPOSES

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Division of Electronic Products

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U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
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Rockville, Maryland 20852

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FOREWORD

This report is one of a series of eight Bureau of Radiological Health staff documents used in the preparation of the "Report to the Congress on Studies Conducted Pursuant to Section 357 of the Radiation Control for Health and Safety Act of 1968, Public Law 90-602." A number of projects were established to study and report on various aspects of radiation control.

The Bureau of Radiological Health, formerly the National Center for Radiological Health, carries out a continuing national program designed to reduce the exposure of man to hazardous ionizing and nonionizing radiation.

The Bureau publishes its findings monthly in *Radiological Health Data and Reports*, Public Health Service numbered publications, appropriate scientific journals, and technical report series for the Bureau's divisions, offices, and laboratories.

The technical reports series allows comprehensive and rapid publishing of the results of intramural and contractor projects. The reports are distributed to State and local radiological health program personnel, Bureau technical staff, Bureau advisory committee members, university radiation safety officers, libraries and information services, industry, hospitals, laboratories, schools, the press, and other interested individuals. These reports are also included in the collections of the Library of Congress and the National Technical Information Service.

I encourage the readers of these reports to inform the Bureau of any omissions or errors. Your additional comments or requests for further information are also solicited.

John C. Villforth

John C. Villforth
Director
Bureau of Radiological Health

PREFACE

The Radiation Control for Health and Safety Act of 1968 requires the Secretary of Health, Education, and Welfare to conduct "a study to determine the necessity for the development of standards for the use of nonmedical electronic products for commercial and industrial purposes." The required study was performed during 1969 and was limited to three classes of products: industrial radiographic and fluoroscopic x-ray units, particle accelerators, and analytical x-ray equipment. The findings are presented in this report.

Robert L. Elder

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ABSTRACT

This report presents the findings of a study conducted during 1969 to determine the need for developing standards for the use of selected nonmedical electronic products for commercial and industrial purposes. Three classes of products were investigated: industrial radiographic and fluoroscopic x-ray units, particle accelerators, and analytical x-ray equipment. For each category the equipment, its typical uses, and the attendant radiation hazards are described, and radiation safety measures are discussed. Existing guidelines and controls for each class of equipment are presented, and incidents involving radiation exposure are reviewed. The need for standards for the use of the equipment is also discussed.

A STUDY TO DETERMINE THE NECESSITY FOR THE DEVELOPMENT OF STANDARDS FOR THE USE OF SELECTED NONMEDICAL ELECTRONIC PRODUCTS FOR COMMERCIAL AND INDUSTRIAL PURPOSES

INTRODUCTION

The "Radiation Control for Health and Safety Act of 1968" requires the Secretary of Health, Education, and Welfare to conduct a study to determine the necessity for the development of standards for the use of nonmedical electronic products for commercial and industrial purposes [P.L. 90-602, section 357 (a) (2)]. This report presents the findings of the study, which was confined to the following three classes of products: industrial radiographic and fluoroscopic X-ray units; particle accelerators, and analytical X-ray equipment.

For each of the three categories of equipment, the equipment is described, its typical uses and the attendant radiation hazards are described, and radiation safety measures are discussed. Also presented is a review of the existing guidance and controls for the class of equipment, including issuances by Federal agencies, State governments, quasi-regulatory organizations, and equipment manufacturers. A review of reported incidents involving radiation exposure is followed by a discussion of the need for standards for the use of these devices.

PARTICLE ACCELERATORS

The term "particle accelerator" is very broad and covers many types of devices. It is generally defined as a device used to impart kinetic energy to electrically charged particles such as electrons, protons, deuterons, and helium ions. In this report, the term refers to devices that accelerate particles to energies greater than approximately 0.5 MeV, as well as neutron generators which operate with a potential of about 0.15 MeV.

Electric fields are used to exert the accelerating force on the charged particles which make up the internal beam of an accelerator. The electric field and the energy it imparts may result from a steady, high, DC voltage (up to several million volts), as in most potential-drop accelerators; it may result from traveling electromagnetic waves, as in electron linear accelerators; or it may be produced by a repeatedly applied lower voltage, as in the cyclotron.

The following sections briefly describe the basic operating principles and applications of the major categories of particle accelerators. The discussion is confined to low and moderate energy accelerators; these are commercially available and are currently used in industry, educational institutions, hospitals, and government facilities. The high energy accelerators, found in the large national laboratories and universities, constitute a small percentage of the total estimated number of accelerators. Furthermore, they are generally under the guidance of Federal agencies which oversee their operation and assure that personnel competent to deal with the complex hazards of these machines are stationed at each facility.

Basic Operating Principles

Potential-drop accelerators use a constant voltage to accelerate particles. They are typically constructed with an ion or electron source inside a "terminal" which operates at a very high voltage with respect to the target area of the machine, which is at ground potential.

The high voltage terminal is mounted on an insulating support referred to as a "column," even though it may be horizontal. The entire high voltage system may be contained in a pressure tank to take advantage of the increase in voltage which can be obtained from the use of an insulating gas under high pressure. Metal equipotential rings surround the column at intervals along its length. The terminal is covered by a smoothly rounded shell to avoid electric field concentrations which would reduce the voltage that can be built up. The accelerating particles pass from the ion source in the terminal through the evacuated accelerating tube. The tube, as well as the insulators of the column, is divided into sections along its length; each section is connected to an equipotential ring. The particles are accelerated through the voltage drop from the terminal to ground (or through two or three times the voltage drop in the case of a tandem machine). Terminal voltages up to about 10-million volts are maintained in the largest pressurized machines. Below about a million volts, pressurization is not required.

Potential-drop accelerators use highly developed special power supplies to generate the high DC voltage, and are usually named according to the type of power supply used. These include the following types: Van de Graaff, Cockcroft-Walton, Dynamitron, resonant transformers, and insulating core transformers.

In an electron linear accelerator (linac) a relatively small amount of energy is required to accelerate the electrons to nearly the speed of light. A further increase in kinetic energy results primarily in increasing the mass of the particle and has little effect on its velocity. Thus, it becomes feasible to produce the accelerating potential by waves traveling at constant velocity, which can be generated in radiofrequency waveguides. Two significant advantages of linear accelerators are (a) particles may be easily introduced at one end and extracted at the other, and (b) the beam which emerges is much superior in definition and particle density to the beam from magnetic accelerators (1). In addition to the electron linear accelerators, a limited number of positive ion linear accelerators are in use.

The cyclotron uses a magnetic field to confine the beam particles to a plane path which is nearly circular. The path is enclosed by one or two hollow semicircular electrodes called "dees" because of their shape. A radiofrequency (RF) voltage is applied between the dees at the frequency at which the ions rotate, which is constant in the conventional cyclotron. As the voltage between the dees alternates, particles are accelerated as they enter and leave the dees. Since the pargicles make many revolutions and acquire energy twice with each revolution, their final energy may be very large compared to the voltages on the electrodes. In potential-drop machines the particles pass through a much larger accelerating voltage, but do so only once or at most a few times; thus, the particles acquire less energy than in a cyclotron.

The betatron is a magnetic-induction accelerator which makes use of a varying magnetic field to accelerate electrons. The principal parts of a betatron are the iron-core magnet, the toroidal vacuum chamber, and the electron injector. In the design of the betatron, the rate of change of the magnet flux and the magnetic field at the orbit radius are controlled so as to maintain a constant radius for the accelerating electrons. The beam is produced in pulses at the frequency of the magnet power, which is usually sixty cycles per second. The betatron is designed to use alternating current (whereas the cyclotron uses direct current). Although betatrons have been constructed which accelerate electrons to 3-- MeV, most are in the 25 to 35 MeV range.

Applications of Accelerators

The major nonmedical applications of accelerators are industrial radiography, activation analysis, radiation processing, and research.

The distinction between conventional X-ray machines used for industrial radiography and accelerators used for the same purpose is not precise. In general, machines generating X-rays above 0.5 MeV are considered to be particle accelerators. The high energy X-rays from accelerators can be used to inspect the interior of thick metal castings and weldments; accelerators have been used for industrial radiography since the early days of World War II. In the heavy steel industry, the resonant transformer has for years been the workhorse in super voltage radiography (2). For penetrating steel up to about 8 inches thick, the Van de Graaff has competed with the resonant transformer. The betatron, with X-ray energies of 10 to 25 MeV, can penetrate greater thicknesses of steel and has been used in radiography of heavy steel castings up to 15 inches thick. The electron linear accelerator, which can produce extremely high X-ray intensities, is used to inspect solid propellant missiles and steel thicker than 18 inches.

Through activation analysis, certain elements can be detected in a substance even though they are present only in trace quantities. The substance to be analyzed is exposed to a flux of energetic particles, usually neutrons, which can be obtained by bombardment of a suitable target with an ion beam from an accelerator. Certain elements, if present, will be made artifically radioactive and can thus be identified by analysis of their radiation.

Several hundred different applications of activation analysis are now routinely used in industry and research. These vary from the determination of parts-per-million amounts of oxygen in steel to the incorporation of trace quantities of an element into a product which may later be nondestructively identified by measurement of the element. The most common accelerator sources of neutrons for neutron activation analysis are the Van de Graaff and Cockcroft-Walton accelerators. The Cockcroft-Walton neutron generator is the most popular type of accelerator for this purpose because of its reliability, simplicity of operation, relatively low cost, and large neutron flux. There are many references available which describe the technique of activation analysis and the accelerator as the source of neutrons (3-8).

Another application of accelerators is in the field of radiation processing. Radiation processing is in an early stage of development and there is a growing interest in commercial applications. However, as with all new processes, it is being adopted by industry only after a careful analysis of cost versus benefit. Potential-drop accelerators are widely employed in current radiation processing applications as well as those under development. Such applications include (9):

1. Curing of surface coatings by irradiation of lacquers and paints.

2. Crosslinking of polyethylene films to produce special wire coatings, insulating materials, heat shrinkable packaging film, and wrappings of improved physical properties.

3. Preparation of specialty copolymers for use as battery separators for Department of Defense requirements.

4. Synthesis of new graft copolymer fibers with improved "crease resistance" and "soil resistance."

Radiation processing can be performed with radiation from either particle accelerators or radioisotopes. At the present time, accelerators deliver 90 percent of the total energy output from radiation sources in irradiation facilities (10). In terms of the sales of processed products, the radiation processing market has been estimated at about $100 million in 1967 and is expected to grow at a rate of 25 percent annually (10). Several excellent references are available on applications of radiation processing and the status of the industry (11-14). Electron irradiation, using energies of 0.3 to 3 MeV, accounts for most commercial applications of radiation processing. Thus, the Van de Graaff, Dynamitron, insulating core transformer, and resonant transformer are the most common accelerators in use for radiation processing.

In 1968, a conference on the use of small accelerators for teaching and research (8) indicated that small accelerators have a wide variety of applications in these areas and that such uses are increasing. The term "small accelerators," as used at this conference, meant primarily Cockcroft-Walton or Van de Graaff machines with accelerating potentials less than 0.5 MeV. One manufacturer has prepared an outline (15) of experiments in atomic and nuclear physics, using a Cockcroft-Walton accelerator as a positive ion source, and a laboratory manual (16) for student experiments, using the same accelerator as a neutron generator. They are intended for use in postgraduate and advanced undergraduate laboratory courses.

One of the oldest applications of accelerators is in the production of radionuclides. At one time, accelerators provided the only means of making radionuclides. At present, most radioactive material is produced in nuclear reactors as a byproduct, but the market for accelerator-produced material is expanding. The cyclotron has been the major source of accelerator-produced radionuclides which, except for target preparation and irradiation services provided by Oak Ridge National Laboratory or the University of Pittsburgh, are being provided by commercial producers.

There is also a class of electron linear accelerators now being developed that will be suited for use in both cancer therapy and the production of isotopes (17).

Because of the very short half-life of the radionuclides needed for medical applications and the difficulty in transporting usable quantities over great distances from accelerators, there is a growing need for the development of commercial cyclotron facilities near large population centers to provide nuclear medicine personnel with the necessary radionuclides (10). The use of iodine-123 as a replacement for iodine-131 for example, can significantly reduce the radiation dose to patients. This becomes even more important when one considers that in 1966, approximately 95 percent of patient administrations for nuclear medical function procedures were performed with radioiodine (18).

From the inventory of particle accelerators compiled by the Bureau of Radiological Health, table 1 indicates the type of facility at which the accelerators discussed in this summary are located (1,19-21).

Table 1. Category of facility at which accelerators are located

Type of accelerator	Location			
	Hospitals and medical centers	Federal Government Labs.	Universities	Industries
	(Percent)			
Cockcroft-Walton neutron generators	2	29	37	32
Sealed tube neutron generators	0	39	26	32
Resonant transformers	22	4	0	74
Insulating core transformers	0	0	0	100
Van de Graaff	11	22	43	24
Dynamitron	0	48	26	26
Linear Accelerators	44	26	13	17
Cyclotron	3	38	57	3
Betatron	42	20	8	27
TOTAL	15	26	29	30

Magnitude of Use

Figure 1 presents estimates of the number of accelerators in the United States, bof both medical and nonmedical use for 1933 through 1972. The data for this figure were obtained from references 1, 19, 20 and 21, from an inquiry directed to the accelerator manufacturers, and from an inventory of accelerators compiled by the Bureau of Radiological Health. As indicated in table 1, medical use of accelerators accounts for approximately 15 percent of the total use, or only 180 of the estimated 1,200 accelerators in the United States today.

The inquiry to the accelerator manufacturers requested figures for sales over the past five years and for expected sales through 1972. The data from all manufacturers were combined and are reflected in figure 1. The inventory of accelerators compiled by the Bureau of Radiological Health is a composite of information from various sources, including publications, State radiological health programs, manufacturer's lists, and personal communications; it contains data on approximately 650 machines. The fact that this number is only about one-half the total estimated for the United States reflects the difficulty of obtaining and maintaining such a list from currently available resources. State health departments have only recently begun to register accelerators and hence become aware of their location and use. Accelerators under Federal control, such as those at Atomic Energy Commission installations, are not under the jurisdiction of the States and must therefore be accounted for separately. Many industrial firms are using accelerators for radiation processing and consider data on the magnitude of use as proprietary information. These and other complications make it extremely difficult to compile an accurate inventory of accelerators.

Accelerator Radiation Hazards

Accelerators are designed to produce intense radiation beams and hence are potentially hazardous to the operators and to others in the vicinity. The type and magnitude of the radiation hazards which exist around particle accelerators will vary according to (a) the type of accelerator, (b) the type of particle accelerated, (c) the energy and beam current of the accelerated particles, and (d) the use of the beam. In summarizing accelerator radiation hazards, it is difficult to categorize the hazards by the type of machine, since the most serious hazards are dependent upon the energy and current of the particles being accelerated and independent of the means of acceleration. For example, a 1 MeV electron beam at a current of 2 mA from a Dynamitron will present the same hazards as a 1 MeV, 2 mA electron beam from a resonant transformer accelerator. The discussion of accelerator radiation hazards and the means of

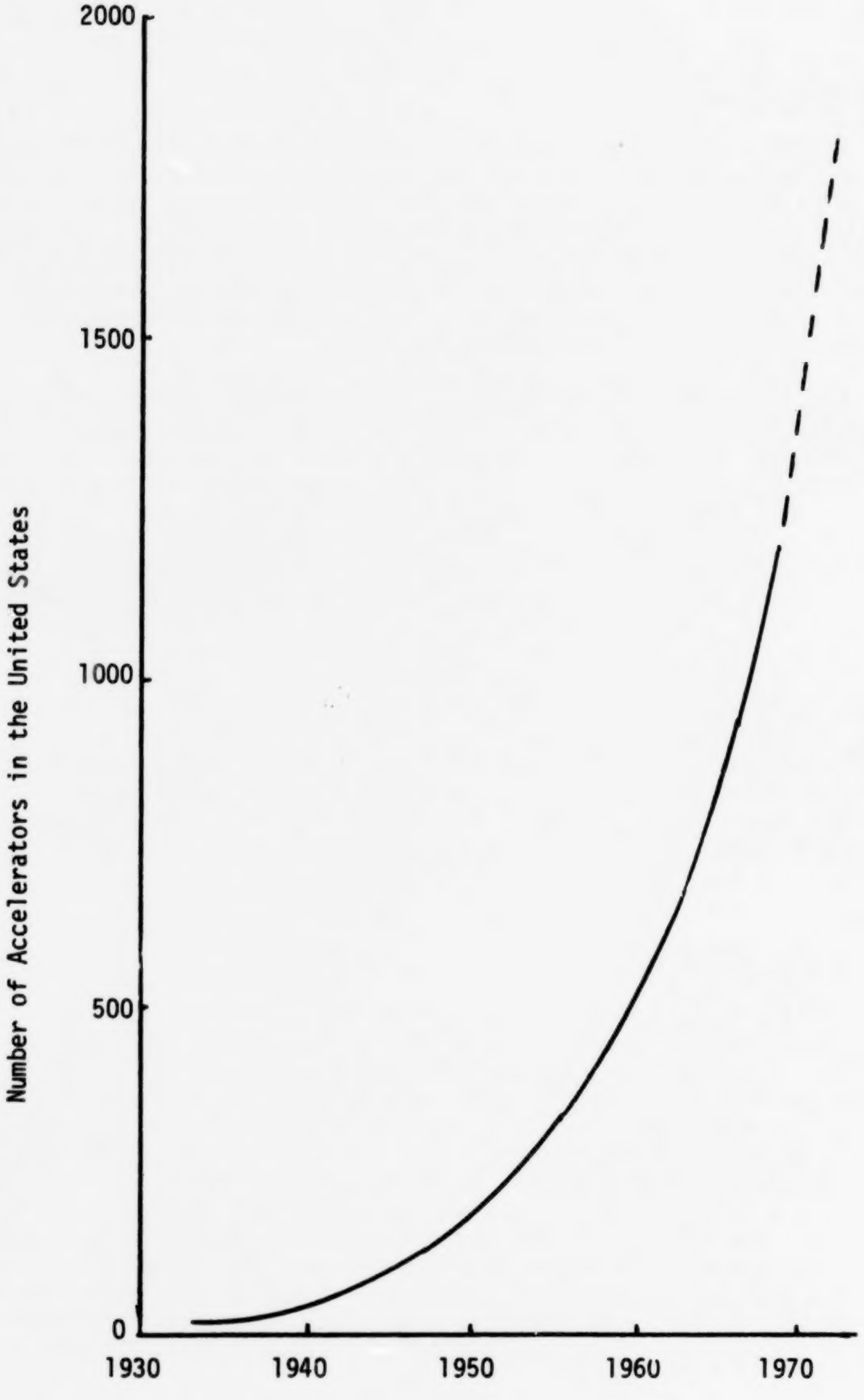

Figure 1. Estimated Number of Particle Accelerators in the United States.

controlling these hazards will therefore be general in nature, treating accelerators as a class of devices. Particular types of accelerators will be specified only if they present special hazards or illustrate a typical case.

The radiations from accelerators are primary radiation, secondary radiation, stray radiation, and induced radioactivity. The first three types, sometimes referred to as "prompt" radiation, cease when accelerator operation is terminated.

The primary radiation consists of the accelerated charged particles, such as electrons, protons, alpha particles, or other heavy particles. The primary radiation exists both as an "internal beam" inside the machine and as an "external beam" which emerges from the accelerator, usually by passing through a thin metal foil at the beam exit port. The external beam is usually focussed to a small diameter and directed onto a target. For these reasons, the primary radiation occupies a very small volume and its energy is very concentrated. Any exposure to the primary radiation presents extreme hazards; even a momentary exposure can cause severe injury or death. The primary particles, as the result of their charge and consequent strong interaction with the electrons of the material through which they pass, have poor penetrating power and can be absorbed by very small amounts of material. It is not difficult to stop primary radiation; however, secondary radiation, which is usually much more penetrating, is produced in the process.

The energy of the individual particles or photons in the secondary radiation is less than that of the primary radiation, but there may be much more secondary radiation and it may be much more penetrating than the primary particles. The secondary radiation is usually either "bremsstrahlung" X-rays or neutrons. These very penetrating radiations are the reason for the large amount of thick shielding which often encloses an accelerator. Often this secondary radiation is the principal useful output of the machine (for example, the X-rays for radiography and the neutrons for activation analysis) and therefore the accelerator is designed to have the highest possible secondary radiation intensity. Electrons, protons, and positive ions are created when the beam strikes a target, but the ranges of these particles are very small compared to that of the other radiation which results. Consequently, little attention need be given to these forms of secondary radiation except in the room containing the target.

Several examples of secondary radiation levels will indicate that, as a general rule, any personnel exposure to this radiation will also be extremely hazardous.

Example 1: A recently developed lightweight linear accelerator, designed for industrial radiographic use, has an X-ray output of 1,500 R/min at 1 meter at an energy of 7.5 MeV (22).

Example 2: Cockcroft-Walton neutron generators produce 14.7 MeV neutrons at yields up to 2.5 X 10^{11} neutrons per second. Calculations for an unshielded machine at this output indicate that the neutron flux dose equivalent (the average flux to deliver 100 millirem in 40 hours) would be produced at a distance of approximately 950 feet from the target.

In addition to the expected radiations from any accelerator, there are other possible sources of radiation which may or may not produce significant levels at a particular installation. Special circumstances or conditions may exist which cause the production of unpredicted and unwanted radiation. Each type of accelerator and each specific design has inherent capabilities for producing stray radiation which are known to the designers or which may be discovered during operation. Stray radiation may occur due to misalignment, backstreaming, or dark current.

If parts of the accelerator are misaligned, a portion of the internal beam may strike the interior of the accelerator and cause stray radiation from an unsuspected area of the machine. This can be especially hazardous under abnormal operating conditions. In many installations, the beam passes through focusing and bending magnets. In case of failure or incorrect adjustment of the magnets, the beam may strike the interior of the accelerator at a point other than the intended target, producing unexpected amounts and types of secondary radiation. Stary radiation of such origin may create a hazard even when the useful beam is at zero intensity and the instruments which monitor the useful beam show small or negligible radiation in the normal radiation areas.

Backstreaming usually occurs in potential-drop accelerators. It is caused by the accelerated beam of charged particles striking the walls and components of the drift tube and releasing a stream of particles of opposite charge that is accelerated in the oposite direction. The backstreaming particles thus cause radiation in the accelerating section of the accelerator. For example, with a Cockcroft-Walton positive ion accelerator, backstreaming electrons will produce X-rays in the accelerating section.

Unintentional or uncontrolled processes may create electrons or ions in an accelerator even when the normal source is turned off. This unintended beam, called "dark current," takes its name by analogy with the current observed through a phototube in the absence of light. Among the mechanisms of unintended electron and ion production are field emission resulting from the high voltage gradients which exist in the accelerating structure, sparks, and ions produced by cosmic rays or radioactive decay.

Although the dark current is ordinarily very small, it may be continuous. The electron or ion source, on the other hand, is often pulsed at a low duty cycle. Thus the average dark current may approach or even exceed the normal average beam current. For example, with a Van de Graaff accelerator the charging supply delivers current to the belt at a moderate voltage by corona from a row of pointed electrodes. These electrodes spray charge uniformly onto the belt. A similar set of electrodes removes the charge at the high voltage terminal. When the charging supply is turned off, no charge is delivered. However, charging the terminal may occur by other effects, such as friction. These stray charges may accumulate at the terminal and develop a very high voltage. This potential on the terminal may be sufficient to accelerate a "dark current" of ions or electrons. Thus this type of accelerator can produce hazardous radiation levels with both the ion source and charging supply turned off, if the belt is running.

It is difficult to predict the levels of radiation in any area of concern without making field measurements; however, it is possible to list the potential types of unwanted radiation for a given application. Table 2 lists accelerator types, the particles accelerated, energy of the particles, and the radiations possible in normally accessible areas for specific uses of the primary beam.

The target which is being intentionally irradiated will frequently become radioactive. Any other material which the beam strikes of which is exposed to intense secondary radiation may also become radioactive. This may include structural walls, experimental apparatus, the atmosphere, and accelerator components. In general, this induced activity is of very short half-life and hence decays rapidly; however, after several years of accelerator operation, long-lived activities may build up which are not appreciably affected by delays of hours or days after shutdown. Table 3 indicates the likelihood of induced radioactivity in the target and vicinity for various particles of different energies.

Air in the accelerator room and the radiation rooms may become radioactive in the following ways:

1. If the beam is allowed to pass through the air, the elements in the air may become radioactive. The radiation intensity produced depends on the beam energy and intensities.

2. Radioactive gases produced internally in the targets may escape into the target area or accelerator room as a result of containment failure.

3. Contamination may be present in particulate or dust form. The contaminating materials may be the result of a ruptured powder target or flaking of activated surface layers of material in the area which has been irradiated.

Table 2. Radiation of possible concern in accessible areas of particle accelerator facilities[a]

Accelerator	Particles Accelerated	Beam Energy (MeV)	Purpose of Operation	Radiation of Possible Concern in Accessible Areas
Potential-drop	Protons Deuterons Alpha Particles	1-10 1-10 2-20	Research Neutron Production Neutron Radiography Activation Analysis	Fast Neutrons Thermal Neutrons Gamma Rays
	Electrons	1-10	Processing Radiography Therapy	Electrons X-rays
Electron Linear	Electrons	1-10	Processing Radiography Therapy	Electrons X-rays
	Electrons	>10	Research Neutron Production Neutron Radiography Activation Analysis	Electrons X-rays Fast Neutrons Thermal Neutrons Gamma Rays
Cyclotron	Protons Deuterons Alpha Particles	15-50 7.5-24 15-50	Research Isotope Production Neutron Production Neutron Radiography Activation Analysis	Fast Neutrons Thermal Neutrons Gamma Rays
Betatron	Electrons	10-50	Radiography Therapy	Electrons X-rays Neutrons

[a] Reference (23).

In addition, an electron beam in air will produce significant quantities of ozone. While not a radiation hazard, ozone is a toxic gas and concentrations in air which exceed even a few tenths of a part per million may cause discomfort to exposed individuals.

Table 3. Accelerated particles arranged according to their propensity for inducing radioactivity, either directly or through their secondary radiation (24)

Particle	Energy range	Induced radioactivity in	
		Target	Vicinity
Electrons	below 1.67 MeV	none	none
Electrons	1.67 to 10 MeV	[a] limited	[a] very slight
Electrons	above 10 MeV	probable	suspect
Protons, helium ions	below 1 MeV	limited	none
Protons, helium ions	1 to 10 MeV	limited	suspect
Deuterons, tritons	any energy	[b] limited	suspect
All ions of light atomic weight	above 10 MeV	probable	suspect

[a] The photodisintegrations of deuterium (threshold = 2.20 MeV), beryllium (threshold - 1.67 MeV), and uranium (threshold 9 MeV) yield neutrons of sufficient intensity that radioactivity may be induced in materials near the source of neutrons.

[b] At energies below 1 MeV, deuteron-initiated nuclear reactions are limited to the following: D (d,n) He^3, T (d,n) He^4, Be^9 (d,n) B^{10}, C^{12} (d,n) N^{13}. Except for N^{13}, all residual nuclei are stable. At any deuterium energy, however, there is the probability that deuterium will be driven into the target material thus causing neutrons bo te produced from the d (d,n) He^3 reaction.

Ancillary apparatus of the more complex accelerators may also add to the radiations present. For example:

1. In certain types of cyclotrons and electron linear accelerators, the particle beam accepted by the main accelerator system is formed and

pre-accelerated in a separate small accelerator. This injector or accelerator usually produces its own primary and secondary radiation and hence presents a personnel hazard when the injector is operated by itself, usually during maintenance.

2. Klystron tubes are used as microwave power amplifiers for electron linear accelerators. The combination of high voltage and high power in these klystron tubes produces conditions for the generation and release of considerable amounts of X-radiation. The importance of this hazard has been shown by one incident in which four persons received exposures of several hundred roentgens from klystron X-radiation (25).

3. Power supplies attached to high vacuum devices, such as rectifiers and vacuum switches, are sources of X-rays. In general, transformer rectifier sets are immersed in oil or in gas pressurized tanks during operation, but care must be taken to assure that the radiations from these power supplies are adequately attenuated so that operating and maintenance personnel are not excessively exposed to the radiations.

Methods of Control

The "Particle Accelerator Safety Manual" published by the Bureau of Radiological Health describes in detail the various hazards and recommended safe practices for common types of accelerators (23). To establish a background for a discussion of the accelerator standards that will follow later in this report, the methods of controlling the radiation hazards detailed in the Safety Manual will be summarized here.

Since accelerators are designed to produce intense primary radiation, the shielding which surrounds these machines is the most important factor in reducing the intensity of the radiation to acceptable levels that will not overexpose persons in the area. Shielding is normally provided around particle accelerators at the time the machines are installed; however, shielding which is adequate at the time of installation may at a later date be inadequate for the following reasons; (a) cracks or other openings in the shielding may occur, (b) the machine may be modified to produce higher beam energies or intensities, or to accelerate different particles, (c) the shielding configuration may be changed, and (d) the shield material, or structure, may deteriorate. Radiation surveys of the area around the shielding must therefore be made periodically. If a defect in the shielding does exist, the background radiation in the immediate area will increase and steps must be taken to locate the defect and make the necessary corrections.

The material chosen for shielding in an accelerator facility usually depends on the dominant radiation from the accelerator and on factors of cost, bulk, and convenience. Heavy materials, such as lead, iron, or steel, are sometimes used for specific localized shielding, such as containers for radioactive materials and shields around accelerator targets. Ordinary concrete is the most common material for general shielding. Concrete contains a mixture of both light and medium elements and, consequently, is effective in several absorption processes. It is usually much cheaper than other materials for comparable results.

There are many processes by which attenuation in the shielding takes place since many reactions can occur between each type of radiation and the materials in the shileding. Usually one type of radiation will be present in much higher intensity than others, or be much more penetrating than others. Shielding which is adequate for this component usually reduces other radiation to negligible levels; however, if the operation of the accelerator is changed, for example by changing targets, the secondary radiation may be different enough to require more shielding.

Most, but not all, of the secondary radiation has the same general direction as the primary beam. Therefore, the shielding required in the forward direction is usually somewhat thicker than that required in other directions. Table 4 is a summary of shielding thicknesses of ordinary concrete required around typical accelerator facilities. This information is illustrative only and is not to be used for design purposes.

To control induced radioactivity in air, as well as ozone and other toxic gases produced by the primary radiation, a ventilation system separate from the building ventilation system must be provided in all hazardous areas. It should exhaust outside the building and be designed so that the irradiation rooms and accelerator rooms are at a lower pressure than other parts of the building. A choice of flow rates may be desirable, so that the rate of flow can be increased during periods of high beam intensity, or before entering the area.

If limited ventilation is provided in hazardous areas, and the concentration of radioactive gases and ozone builds up during an irradiation, time must be allowed for the activity or gas concentration to fall to permissible levels before entering the hazardous area.

Electronic interlocks are electrical circuits which act to turn off electrical power and/or prevent it from being turned on, if a hazardous situation exists. An accelerator usually has many interlocked subsystems and each interlock is intended to furnish protection to personnel or equipment in the event of a specific malfunction or improper operating condition. The interlock system which deals with radiation hazards must prevent access to areas in which unsafe radiation levels are produced by the accelerator and must prevent operation of the accelerator if such operation produces an unsafe radiation level in any occupied area.

Table 4. Typical radiation shielding for particle accelerators (D)

Accelerator Type	Internal Beam	Beam Energy (MeV)	Average Current (μamp)	Radiation To Shield	APPROXIMATE SHIELDING REQUIREMENTS (A) (inches of ordinary concrete, 147 lb/ft^3)				
					Forward	Rear	Side	Top (B)	Base
Potential-drop	Deuteron	0.1	100	14 MeV Neutrons	16	16	16	16	(C)
	Deuteron	0.4	100	14 MeV Neutrons	30	30	30	30	(C)
	Deuteron	0.5	1000	14 MeV Neutrons	58	58	58	58	(C)
	p, d, α	1	1000	Stray X-rays (E)	(H)	12	8	8	8
	p, d, α	2	750	Stray X-rays (E)	(H)	18	12	12	8
	p, d, α	3	750	Stray X-rays (E)	(H)	36	30	30	8
	Electron	1	1700	X-rays	30	30	30	30	(C)
	Electron	2	1000	X-rays	42	40	40	40	(C)
	Electron	3	1000	X-rays	57	40	50	50	(C)
	Electron	6	100	X-rays	74	52	63	63	(C)
Linac	Electron	6	10	X-rays	60	38	50	50	(C)
	Electron	8	40	X-rays	87	60	72	72	(C)
	Electron	20	360	X-rays	131	95	95	95	(C)
Cyclotron	Proton	15	100	Neutrons	48	48	48	48	(C)
Betatron	Electron	20	---	X-rays (F)	82	27	47	47	(C)
	Electron	20	---	X-rays (G)	100	45	65	65	(C)
	Electron	30	---	X-rays (F)	85	28	50	50	(C)
	Electron	30	---	X-rays (G)	105	46	67	67	(C)

(A) Assuming approximately 25 feet from target to occupied area

(B) Top Shielding assuming areas above the accelerator are occupied and distance from the target to the occupied area is the same as the geometry to the side.

(C) Base Shielding not required if accelerator is mounted on the ground floor.

(D) This information is to be considered only illustrative and is not to be used for design purposes.

(E) Neglecting Neutrons

(F) 10^2 R/min @ 3 ft. from target

(G) 10^3 R/min @ 3 ft. from target

(H) Target dependent

Each of the individual interlock functions acts to open or close a pair of electrical contacts, either directly or through a relay. Many pairs of contacts in series must be closed to provide control power for the "beam on" switch. Subsystems often have smaller series chains, which culminate in a single pair of contacts in the main interlock chain. There is a great deal of variation in the interlocking arrangements to be found in different accelerators. This is due to the inherent differences in design philosophy, cost factors, and user requirements. Ideally, the interlock system should be "fail-safe" in the sense that defects or component failures in the interlock chain itself will prevent operation of the accelerator.

In nearly all accelerators, a key-operated switch is incorporated in the beam controls. The key to this switch is frequently designed to unlock the door or gate leading to the target area. Thus the beam must be turned off and the key removed from the switch before anyone can enter the area of most extreme hazard. In accelerator facilities where there are two or more entraces to the target area or more than one irradiation room, more elaborate key-switch circuits are often used. Also, additional switches, which are closed only when doors, gates, shielding plugs, and shielding doors are in a safe condition, may be used in series with the key switch. One or more disabling switches must also be installed in target areas and experiment rooms, so persons in those areas can turn off the accelerator or prevent the beam being turned on, in the event that they are trapped when someone else attempts to turn on the beam.

In addition to interlocks to prevent inadvertent entry to hazardous areas during acceleration operation, warning devices such as lights, signs, and audible devices must be used to inform people of the machine status. The placement of status lights is important; they should be located in the accelerator vault, irradiation rooms, corridors leading to the irradiation rooms, and on the control console. The status lights should indicate magnet status, beam status, and any other condition considered important for the safety of operating personnel. Signs are also used to mark areas where hazardous radiation levels could exist. Because of the frequent changes in radiation level and beam usage in experimental areas, temporary signs and barriers which are readily movable are used to indicate these changing conditions. Horns, or other audible devices, are used to indicate that the beam is on or about to come on. Public address systems announcing the impending turning on of the radiation beam are also sometimes used in addition to the audible warning signal.

Even with adequate radiation shielding, interlocks, and warning systems, there is no substitute for frequent radiation surveys in areas where radiation hazards are suspected. Radiation survey data must be accumulated during installation of the accelerator and during the first routine operations, since the two may be widely different. The radiation survey should be directed toward measuring the distribution of exposure and magnitude of exposure rates in all occupied areas when the beam is on, and residual radioactivity in the irradiation room and accelerator room when the beam is off.

The last item in this brief summary of methods for controlling accelerator radiation hazards is the health physics or radiation safety program at the accelerator facility. Such a program must consider the physical plant and the procedures that employees follow in the day-to-day operation of the facility. The obvious goal of such a program should be to protect the workers and the general public from unnecessary radiation exposure. This may be accomplished by the proper design of the facility to include adequate shielding, the installation of safety interlock systems, and the establishment of standard operating procedures. The safety procedures that should be defined, written down, and properly posted for each accelerator facility include:

1. Responsibilities for the safety program.

2. Startup and shutdown procedures for the accelerator, including those related to radiation safety.

3. General procedures to be followed while the accelerator is in operation, such as necessary radiation surveys, security of controlled areas, wearing of personnel dosimeters, and so forth.

4. Procedures to be followed when the accelerator is in a secured or shutdown condition, such as those related to handling activated targets.

5. Emergency procedures, including phone numbers of appropriate personnel.

6. Circuit diagrams of the safety systems to be sure that when changes are made, they do not adversely affect other functions.

7. Records of radiation surveys, inspections and maintenance performed on the accelerator.

ANALYTICAL X-RAY EQUIPMENT

X-ray diffraction techniques are based on an analytical procedure which was developed in 1912 and has constantly grown more sophisticated and complex since that time. A related technique — the investigation of materials by observing the fluorescent X-radiation — was begun in the late 1800's; however, modern X-ray fluorescence spectrographic methods were not developed until around 1950. Analytical techniques utilizing either X-ray diffraction or X-ray spectrography involve the production and measurement of low-energy X-rays and the analysis of their characteristics. The application of these techniques has served to replace many time-consuming wet chemistry procedures for qualitative and quantitative analysis. X-ray spectrography is used for determining the atomic composition of materials, while X-ray diffraction may be used to analyze their molecular makeup. Each of these analytical methods is nondestructive, yet offers a high degree of accuracy. X-ray diffraction may also yield information on the microstructure of a material being investigated. Both methods are primarily laboratory techniques for investigating materials and, as a result, analyses are usually performed by laboratory personnel. However, on-line industrial functions may also be performed with either of these methods. Analytical X-ray devices have many industrial uses involving such products as petroleum, chemicals, metals, ores, rubber, and electronic components.

X-ray Diffraction Equipment

Basic Operating Principles. X-ray diffraction equipment operates on the principle that the electrons associated with the atoms of a crystal scatter, or diffract, an incident X-ray beam in a certain manner. If a narrow beam of X-rays is directed into a crystalline substance, the emerging diffracted rays may be used to record a pattern on film. The pattern formed by the diffracted rays is characteristic of the crystalline structure of the specimen. It is therefore possible to use X-ray diffraction for identification of crystalline material or changes in crystalline structure.

Many methods have been devised for recording the diffraction pattern on film. Figure 2 shows the Laue method, in which the primary beam passes through a single crystal. A flat film is used to record those rays which are diffracted in the forward direction. The primary beam is usually stopped at the film with a small piece of lead, to prevent unnecessary fogging of the film. Figure 3 shows a back reflection method, which is used when the specimen is too thick for adequate penetration of the X-ray beam. In this method, the X-rays reflected back toward the X-ray source are recorded on a film. Figure 4 shows a method in which a powdered specimen is used. The sample is placed in a fine glass capillary or on a material transparent to X-rays. The diffracted rays are recorded on a strip of film which is placed around the specimen.

The diffraction pattern on the film can be analyzed by comparison with known standard patterns or analyzed by application of a relationship known as Bragg's Law (26).

An alternate, nonfilm, method of recording the diffracted X-rays provides faster, more accurate results. This method, called diffractometry, utilized a detector which is rotated in an arc around the specimen;

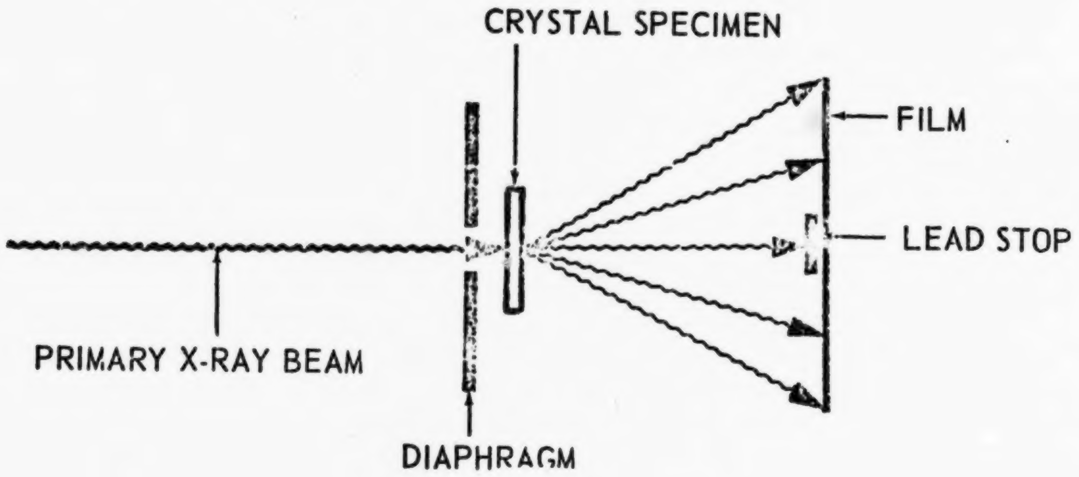
CRYSTAL SPECIMEN
FILM
LEAD STOP
PRIMARY X-RAY BEAM
DIAPHRAGM

Figure 2. Lane Method-Heterogeneous X-rays and Stationary Crystal.

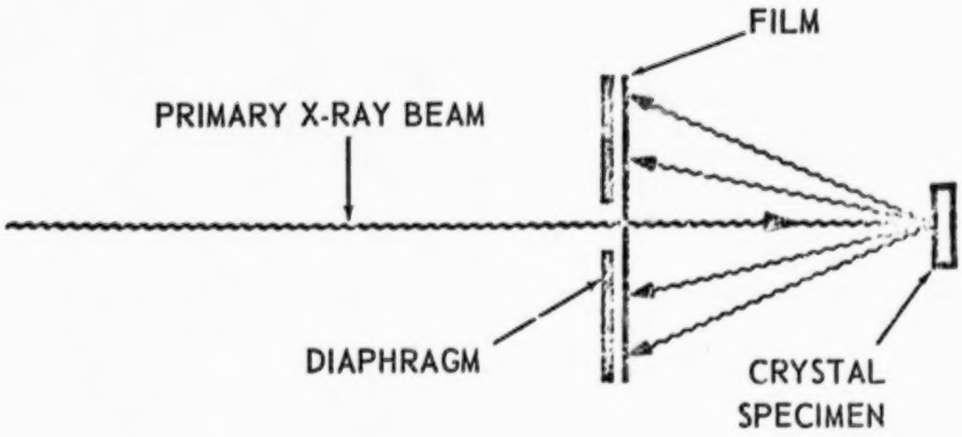
FILM
PRIMARY X-RAY BEAM
DIAPHRAGM
CRYSTAL SPECIMEN

Figure 3. Back Reflection Method.

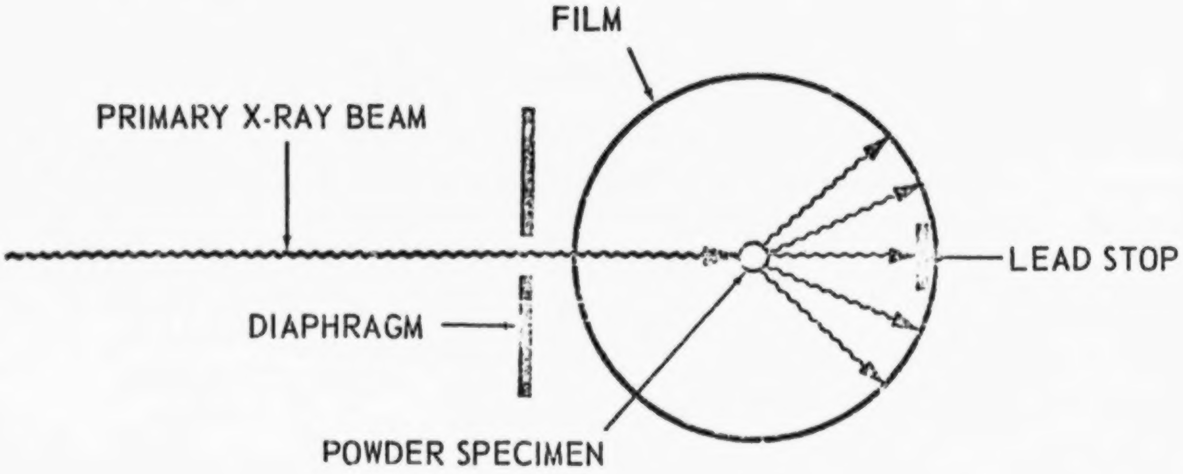
FILM
PRIMARY X-RAY BEAM
LEAD STOP
DIAPHRAGM
POWDER SPECIMEN

Figure 4. Powder Method.

the detected impulses are amplified and recorded as peaks on a paper strip chart. The recorded peaks, which correspond to diffraction lines on a film, may then be used for both qualitative and quantitative analysis of the specimen. This method is depicted in Figure 5.

The X-ray tubes in diffraction equipment usually have three or four exit ports, all of which may be used simultaneously, so that several of the above procedures may be carried out at once. A wide variety of target materials is used in X-ray tubes for diffraction equipment. The target material is chosen to provide emission spectra suitable for the specimen to be analyzed.

Radiation Hazards. X-ray diffraction studies require well-regulated, low-energy X-rays. These are obtained from X-ray tubes which operate at a maximum of about 50 kV. Maximum tube current is about 45 mA when operating at lower voltages. These tubes have very thin windows which are usually made of beryllium.

The thin windows allow the passage of a high flux of low energy or "soft" X-rays, resulting in exposure rates up to 3 X 10^6 roentgens per minute at the tube housing port (27-29). The intensity of the primary beam at a given point in the beam increases as either the tube voltage or tube current is increased (30). Under most operating conditions the primary radiation beam will be of sufficient intensity to cause serious radiation injury to parts of the body which are in the beam for short periods of time

Exposure rates for scattered radiation vary greatly according to the physical arrangement of the diffraction apparatus and the rates are unsymmetrical around the apparatus. One study has revealed that levels up to 50 roentgens per hour were present near the diffraction apparatus in an area where the operator's fingers may be during equipment adjustments (31). Simultaneously, a rate of 150 milliroentgens per hour was measured in the area of the operator's head.

An X-ray diffraction unit may simultaneously radiate four very small beams of low effective energies. The beams are frequently in a horizontal plane, about four or five feet above the floor. These machines may be operated continuously for periods ranging from a few minutes to many hours.

Some of the most common causes of unnecessary radiation exposures from X-ray diffraction equipment are as follows:

1. Placement of fingers in the primary beam while changing samples because of failure to either block the primary beam or stop X-ray production.

2. Visual beam alignment without using a leaded glass shield. This may result in the primary beam directly striking the eye for prolonged periods.

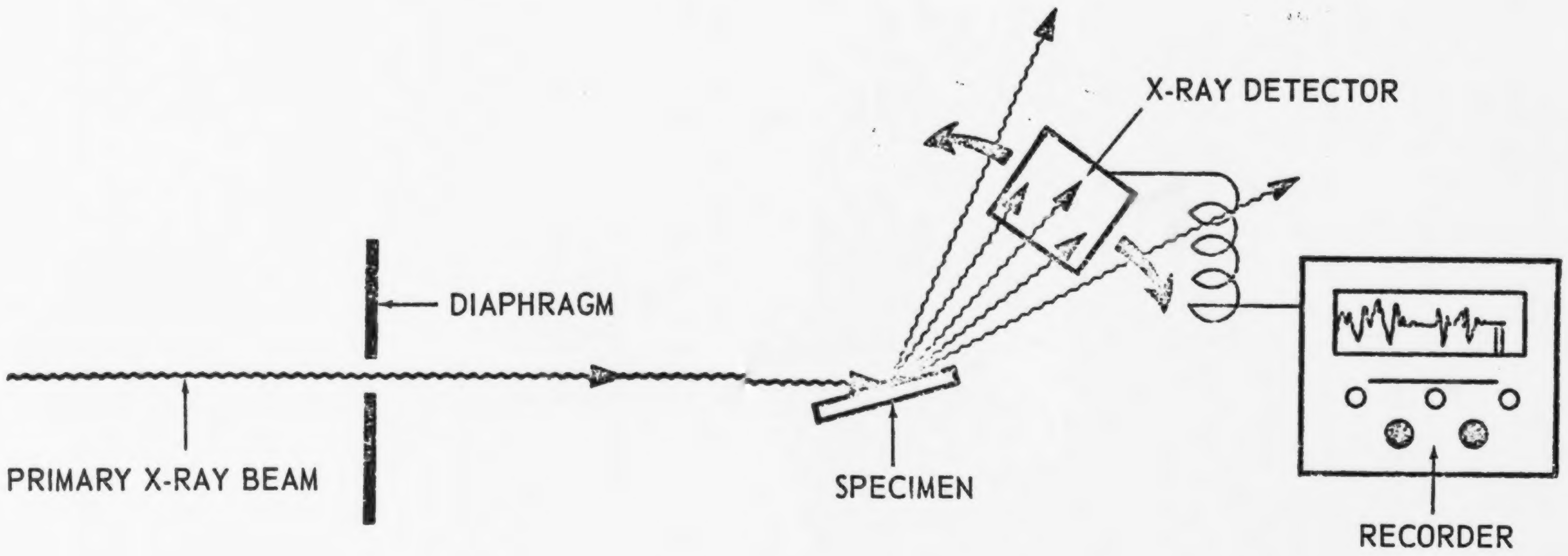
X-RAY DETECTOR
DIAPHRAGM
PRIMARY X-RAY BEAM
SPECIMEN
RECORDER

Figure 5. X-ray Diffractometer.

3. Failure to realize that X-ray beams are being emitted from exit ports other than the one of immediate concern.

4. Unattended operation of the unit in an uncontrolled area. Personnel who are unaware that the unit is operating may stand near or pass through areas of high scatter radiation levels.

5. Alteration or removal of shielding in order to perform a specialized analysis.

6. Installation or modification of equipment by manufacturers' representatives who perform final adjustments, and so forth, with the unit partially disassembled.

The risk of radiation overexposure due to the above causes may be significantly reduced by constant vigilance on the part of all users.

Safety Devices. The following are descriptions of some safety devices which are available for use on some or all X-ray diffraction units:

Console warning light: This light, usually red, is customarily lit when X-rays are being produced, but not necessarily **released**. It is located on the main control panel and frequently has a small caption, either on or adjacent to the light, which reads "X-ray ON," or a similar statement. This light and warning caption are often small and may not be conspicuous. In some models, the unit becomes inoperable if this light burns out.

Console key: This key is located on the main console and must be in the "ON" position before the high voltage can be turned on.

Shutter warning signal: This signal, usually a light, is located somewhere near the X-ray tube and should indicate when a shutter is opened, in which case the X-ray beam may be released. Ideally there is one signal for each shutter.

Interlocks: Interlocks may be used in a number of locations, depending on the type of unit and the accessories being used. The purpose of interlocks is to either deactivate the X-ray tube or cause the X-ray beam to be blocked if an unsafe condition exists. For example, interlocks may be located so as to turn off the X-ray tube when an X-ray exit port is uncovered and there is no camera in position to receive the X-ray beam.

Removable shielding: Some diffraction accessories require the removal of shielding before manipulating the specimen. Such shielding is simple in construction and easily removable. It is most often used to reduce the amount of scatter radiation in the vicinity of the operator and is sometimes interlocked so that X-rays cannot be produced when the shield is not properly positioned.

In situations where parts of the diffraction apparatus must rotate during the analysis procedure, it may be difficult to utilize either permanent or temporary shielding. As a result, shielding is frequently inadequate in these situations.

Radiation Monitoring. Personnel film badges usually fail to correctly indicate radiation exposure from X-ray diffraction machines because (a) the beam is extremely narrow, (b) the film badge is normally not worn at a height comparable to that of the X-ray beam, and (c) the film badge may be inefficient for monitoring "soft" radiation such as emanates from X-ray diffraction equipment (27,28). The merit of using film badges is thus debatable and it has been argues that their use may actually create a false sense of security.

Radiation measuring equipment used in attempts to monitor stray or promary radiation from X-ray diffraction equipment may also be misleading. Most radiation monitors are designed to detect and measure fairly energetic X-rays, such as those utilized in medical radiographic procedures. However, X-rays from X-ray diffraction machines are much less energetic, which may result in a false interpretation of readings from the radiation monitor. As a result, radiation levels may be considerably more intense than those indicated by the radiation monitor (31).

X-ray Spectrographic Equipment

Basic Operating Principles. When an element is exposed to X-rays of sufficient energy it will produce secondary, or fluorescence, X-rays. Each element has a unique X-ray spectrum which may be used to identify that element. The X-ray spectrograph, or fluorescence apparatus, consists of three fundamental components, as illustrated in figure 6. They are (1) a high intensity X-ray tube from which X-rays are directed to the specimen being analyzed, (2) an analyzing crystal which reflects each wavelength at a different angle, in accordance with Bragg's law, and (3) a radiation detector which may move in an arc around the crystal. The monitored intensities are then recorded. The X-ray tube target and analyzing crystal are selected to match the characteristics of the specimen. When analyzing specimens of low atomic number, it is essential to reduce the air absorption of X-rays. For such applications, vacuum techniques are employed, necessitating an enclosed X-ray path.

Radiation Hazards. X-ray spectrographic units generally operate at slightly higher voltages than diffraction units, but produce a similar radiation spectrum. As with diffraction units, the intensity of the primary beam increases as either the tube voltage or tube current is increased (30).

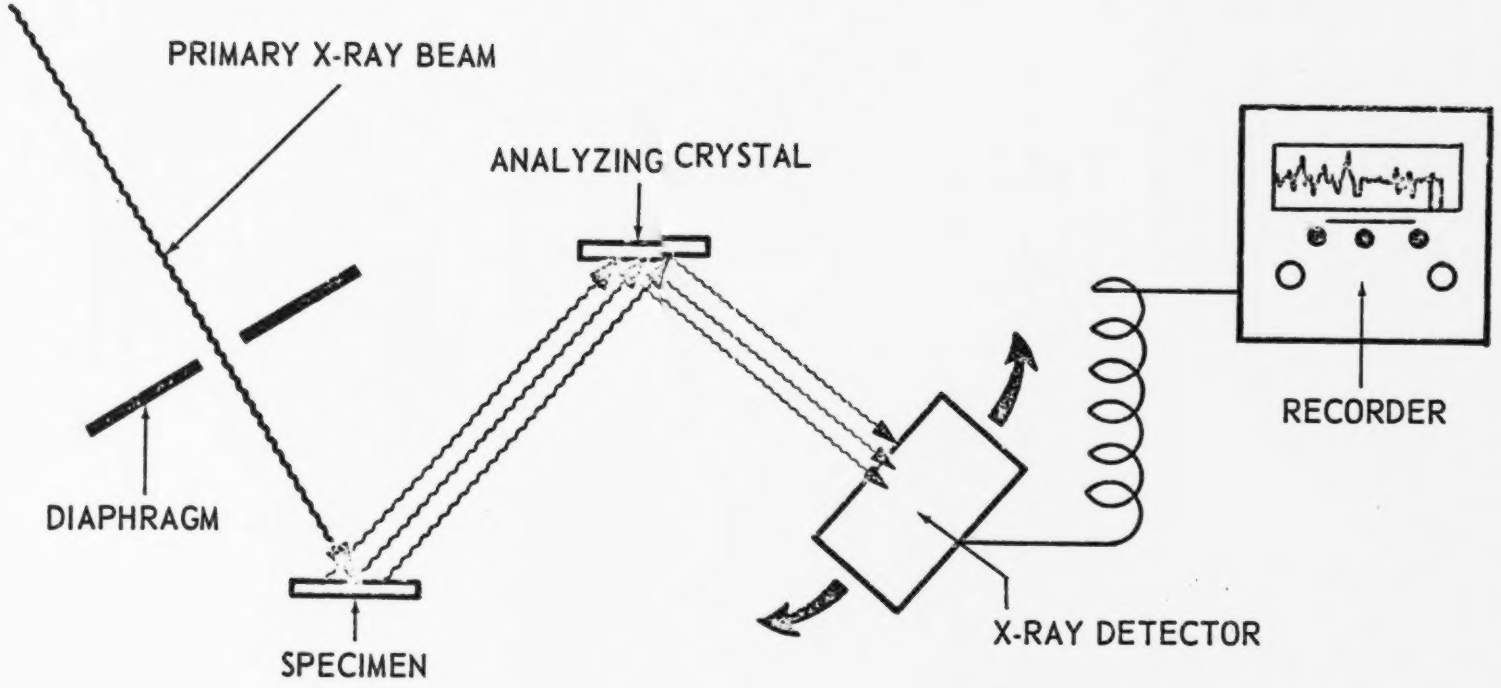
PRIMARY X-RAY BEAM
ANALYZING CRYSTAL
DIAPHRAGM
SPECIMEN
RECORDER
X-RAY DETECTOR

Figure 6. X-ray Spectrograph.

Stray radiation levels are often lower than those around X-ray diffraction units. One reason is that vacuum systems are often employed to keep the specimen chamber free of air; the walls of such systems also serve to prevent the escape of X-rays. Automatic specimen changers are usually used and it is thus unlikely that the operator's hands will be in areas of high primary and stray radiation; however, not all spectrographic units utilize a vacuum system and stray radiation may present a hazard. One investigator has reported an exposure rate of 15 roentgens per minute in the area where the operator's fingers could be during specimen changes (28). This investigator also reported a radiation level of about 1 roentgen per hour at the control panel of one machine.

The radiation hazards and safety devices for X-ray spectrographic units are, in general, the same as those for X-ray diffraction equipment. Due to the higher operating voltages, the X-rays are more penetrating and the radiation levels are more intense; however, this presents no significant additional shielding problem since the radiation involved is of relatively low energy.

Magnitude of Use

There is no known source of accurate data on the number of analytical X-ray units presently in use in the United States. Data from the 1968 "Report of State and Local Radiological Health Programs" (32) reveal that at least 2,500 analytical X-ray units (this figure does not include units used in Federal facilities) were known to be in existence in the United States; however, only 38 States (76 percent) responded to this poll and the numbers given by several of the respondents were obviously conservative estimates. The actual number of analytical X-ray machines is probably closer to 5,000 (33).

A survey of known manufacturers of analytical X-ray equipment who distribute within the United States was made to determine past sales volume and the future trend. During the past five years a total of about 1,100 X-ray diffraction units were sold to American users and it was projected that an additional 1,100 will be sold during the next three years (through 1972). X-ray fluorescence equipment sales for each of these periods are estimated to be 20 to 35 percent lower than for diffraction equipment, again based on data supplied by manufacturers.

Information obtained from the National Electrical Manufacturers Association indicates that approximately 1,800 low voltage X-ray tubes are sold annually and probably 80 percent of these are used in analytical X-ray units. It should be noted that some of these tubes are used as replacements and that others may be used alternately in the same machine for experimental reasons.

INDUSTRIAL RADIOGRAPHIC AND FLUOROSCOPIC EQUIPMENT

Inspection of objects through the use of X-rays had its beginning on November 8, 1895 when Wilhelm Konrad Roentgen discovered X-rays. In his first observations he used a fluorescent screen to visualize the interior structure of objects. Later he replaced the fluorescent screen with a photographic plate to permanently record the effects of the new rays. He reported his findings in 1896 in the annals of the Wurzburg Physical – Medical Society.

The production of X-rays occurs when electrons, which have acquired large amounts of energy from acceleration across a high voltage, are suddenly slowed by collision with a target. The potential difference ranges from thousands to millions of volts, causing the electrons to traverse the space between the cathode (the source of electrons) and the anode (the target where X-rays are produced).

All industrial X-ray equipment, regardless of use, involves high voltage circuits and dense targets for the production of X-rays. The specific X-ray testing techniques will determine the configuration of these components in a particular unit. The inspection procedures, as well as the operator's understanding and his practice of appropriate radiation safety procedures, will determine the potential hazards to humans from the operation of such equipment. This section will describe, in general terms, the uses of specific types of industrial X-ray generators, typical operating parameters, and the associated radiation hazards.

Applications

Radiography is a general term applied to the method of inspection where X-rays or gamma rays are directed at the object to be inspected; the transmitted rays expose a photographic film which retains a permanent image (fig. 7).

In fluoroscopy, the photographic film is replaced by a fluorescent screen. There are three primary methods or systems by which the image is viewed in fluoroscopy. The simplest is direct viewing, which requires the use of a fluorescent screen which emits visible light when exposed to X-rays. The inspector can view the fluorescent screen with mirrors in order to avoid being exposed to the direct beam (fig 8). Since the light output from a fluorescent screen is very low, two methods have been developed to assist the operator in his inspection. One, the image intensifier system, brightens the image and projects it onto another fluorescent screen which can be observed directly, or remotely using a closed circuit TV system. The other method of fluoroscopic image viewing utilizes an X-ray sensitive vidicon. The image is viewed remotely using a TV monitor.

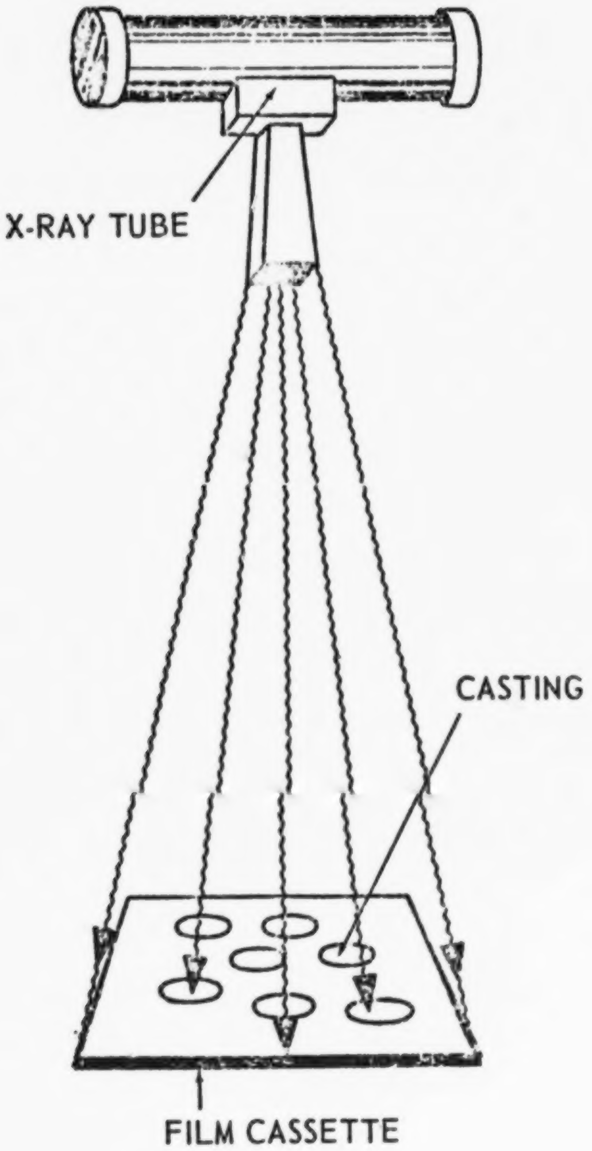
X-RAY TUBE
CASTING
FILM CASSETTE

Figure 7. Diagram of the Radiographic Procedure.

NOT REPRODUCIBLE

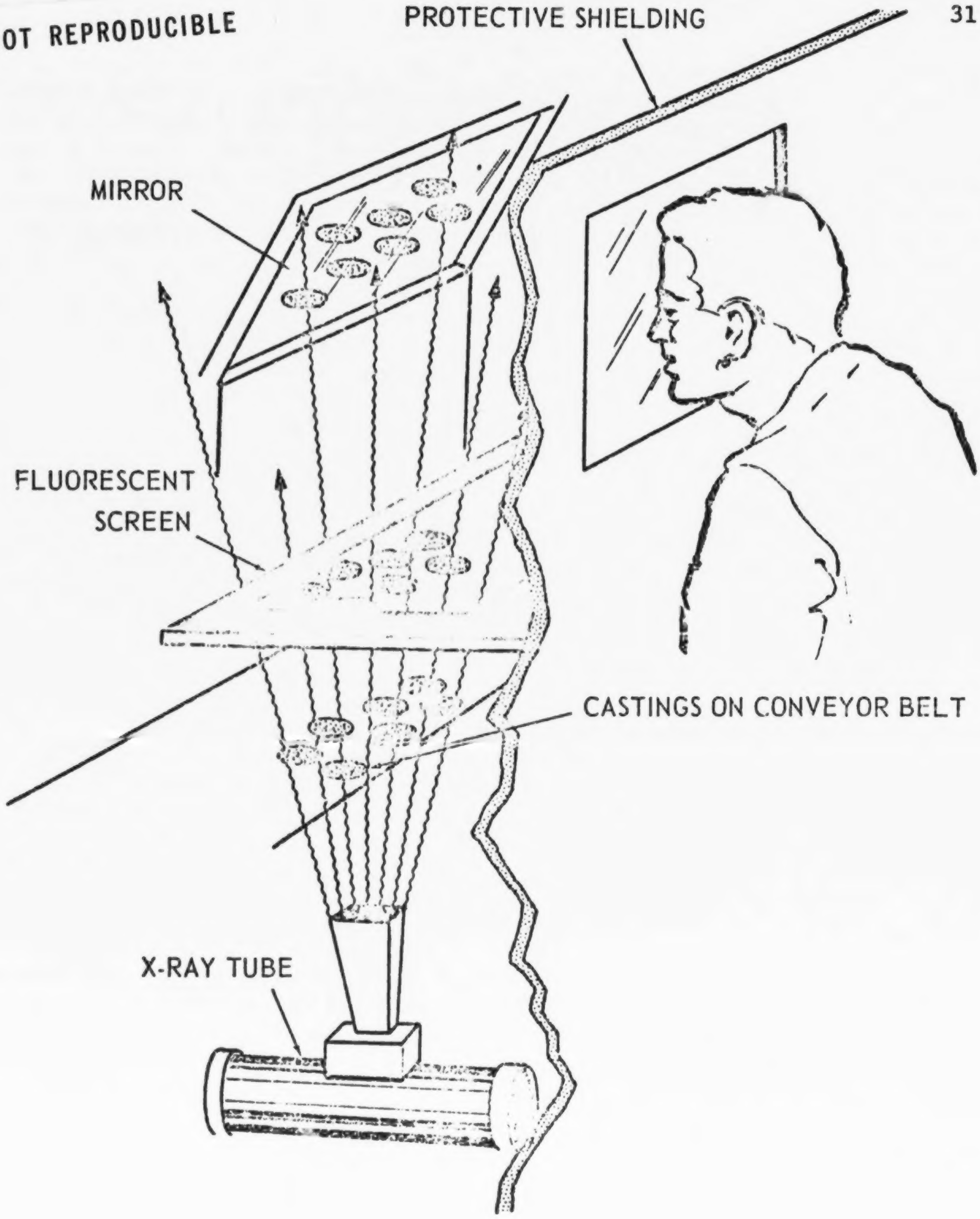
PROTECTIVE SHIELDING
MIRROR
FLUORESCENT SCREEN
CASTINGS ON CONVEYOR BELT
X-RAY TUBE

Figure 8. Diagram of the Fluoroscopic Procedure.

X-rays are produced over a wide range of voltages. The most common industrial X-ray machines in use today are the low energy machines which operate with a maximum voltage below 300 kilovolts. Most portable X-ray machines are low voltage units; higher voltage circuits require more insulation and larger transformers, greatly increasing the weight. Nevertheless, some portable machines have been developed which operate at up to 400 kilovolts peak (kVp).

Many of the low energy units, both stationary and portable types, have an X-ray tube port (window) of beryllium metal. This allows the very soft (low energy) radiation which is easily absorbed in matter to remain in the usable X-ray beam. Some of these low energy units may also produce high intensity X-ray beams through the use of high tube currents (about 50 milliamperes). Such units are used in sterilization and irradiation of materials. X-ray machines which use lower tube currents (about 5 milliamperes) are generally used for the inspection of welds in thin steel or low density materials such as aluminum or magnesium. Other uses of these units include inspection of plastics, paintings, art objects, leather, paper, ceramics, graphite, rubber, precious stones, electronic circuitry, seeds, insects, small animals, and microradiography.

As stated previously, increased voltage in an X-ray unit requires increased weight because of larger power supplies and increased insulation and shielding requirements. Such heavy units are generally permanently installed in a room and the material to be inspected is brought to the unit. Medium energy units, which operate at maximum voltages between approximately 200 and 300 kilovolts, are usually used in radiography although some fluoroscopy units have been made in this energy range. The higher voltages enable the X-rays to penetrate thicker or more dense materials. Because of this, these units are used for inspection of weldments, castings, and other materials which require more penetrating radiation.

Units which operate between 300 and 500 kilovolts maximum are termed high-energy units and are used in the inspection of even thicker or more dense materials. These units often are designed to run continuously; exposure times of an hour or longer are common in industrial radiography.

Magnitude of Use

It has been estimated that there were 3,000 users of industrial X-ray equipment in the United States in 1967 (34); in 1968 an estimated 10,000 industrial radiographic and fluoroscopic X-ray units were in use (35). A study made in 1969 indicates that only about 5,800 of these units were registered by the various State and local radiological health programs (36).

While the exact figures are not known because of difficulty in obtaining the data from manufacturers, it is estimated that about 600 units were sold in 1969 and that this rate of sales will continue through 1972. This means that the number of industrial units in use by 1972 will be approximately 12,000.

A query of the X-ray tube manufacturers shows that they expect to manufacture about 12,500 tubes between 1969 and 1972.

Radiation Hazards and Control

The hazards involved in the use of an industrial X-ray machine are a function of the manner in which the machine is used. For the purposes of this study, machine setups may be categorized as (1) cabinet X-ray installations, (2) shielded X-ray rooms, and (3) portable X-ray installations.

Cabinet X-ray Installations. The least hazardous situation is presented when the unit involved is in a well-shielded enclosure. The X-ray tube and the object to be irradiated or inspected are both inside a permanent enclosure which is small enough to prevent a person entering it. Interlocks are provided so that the production of X-rays will terminate if the enclosure door is opened during an exposure. Such units are termed cabinet radiographic or fluoroscopic installations and they are generally low power units which may use beryllium window tubes. There is no limit placed on the power of the unit that is used in this type of installation and often the enclosure is built by someone other than the person or company which makes the X-ray machine. The X-ray intensity emitted by units with beryllium window tubes is quite high. At 50 kVp and a tube current of 20 mA, these units can produce approximately 100,000 R/min. at two inches from the tube target.

Cabinet X-ray units are designed to be used where people are working in adjacent areas. Because of this, the shielding used in the installation is usually sufficient to attenuate the radiation to acceptable levels a short distance from the outside surface of the enclosure. Interlocks are provided, as mentioned above. Warning or indicator lights are often provided to show when X-rays are being produced.

With these safety features, the potential dangers to the operator are usually limited to the failure or intentional circumvention of such features. If the enclosure is damaged by dents or holes in the shielding, for instance, the shielding material could fail to attenuate the radiation properly. Also, if the interlocks should fail or be intentionally defeated, the operator could receive a high exposure. The magnitude of the exposure would depend upon his exact position with respect to the enclosure. He could receive an extremely high exposure from the direct beam or he could receive a lesser amount from the scattered radiation through the open door of the unit.

Shielded X-ray Rooms. A more hazardous situation arises in the case of shielded X-ray rooms. These X-ray inspection rooms are arranged so that the X-ray tube and the object to be exposed are located within a permanent enclosure in which no one is allowed to remain during the exposures. This type of installation is usually constructed for the stationary or limited mobility type of radiographic unit, especially those operating in the medium and high energy ranges; however, low energy units may also be used. The operating parameters of machines used in this type of installation are: maximum operating voltages approximately 100 kVp and above, tube currents generally around 10 mA, and exposure times up to hours. The hazards are greater than with the cabinet units because the installation is larger, more powerful X-ray units are used, and the structural shielding of the tube housing is usually less. The main concern is to prevent occupancy of the enclosure while exposures are made. Inside the enclosure, a person could be exposed to various levels of radiation depending upon his location in the room, the type of material being inspected, and the beam collimation. The direct beam of an X-ray machine operating at 120 kVp and 10 mA produces approximately 15 R/min at one meter from the X-ray tube. A medium energy unit operating at 250 kVp and 5 mA may put out about 22 R/min at one meter.

Many industrial X-ray machines are designed to produce a 360° beam for panoramic radiography. In one use, the beam is directed in a plane parallel to the floor and numerous radiographs are made simultaneously (figure 9). This presents a more hazardous situation than the collimated beams generally used in radiography because the direct beam is not confined to a small area.

While fluoroscopy is most often performed in cabinet installations, it is also used in shielded rooms. It is usually limited to light metals and articles of lower density, such as rubber tires; however, such procedures as the inspection of longitudinal pipe welds are also performed. These installations generally employ indirect viewing methods and techniques using less than 250 kVp.

The direct beam of an X-ray machine obviously produces high levels of radiation from which the operator must be protected. Scattered radiation also constitutes an exposure problem. The amount of scattered radiation is dependent upon the size of the radiation field, the number of atoms present in the scattering object, and the angle between the direct beam and the point of measurement (37). The maximum energy of the scattered radiation is always less than the maximum energy of the beam radiation. A rule of thumb for estimating the amount of scattered radiation is as follows: The exposure rate of radiation scattered from a beam at 90°

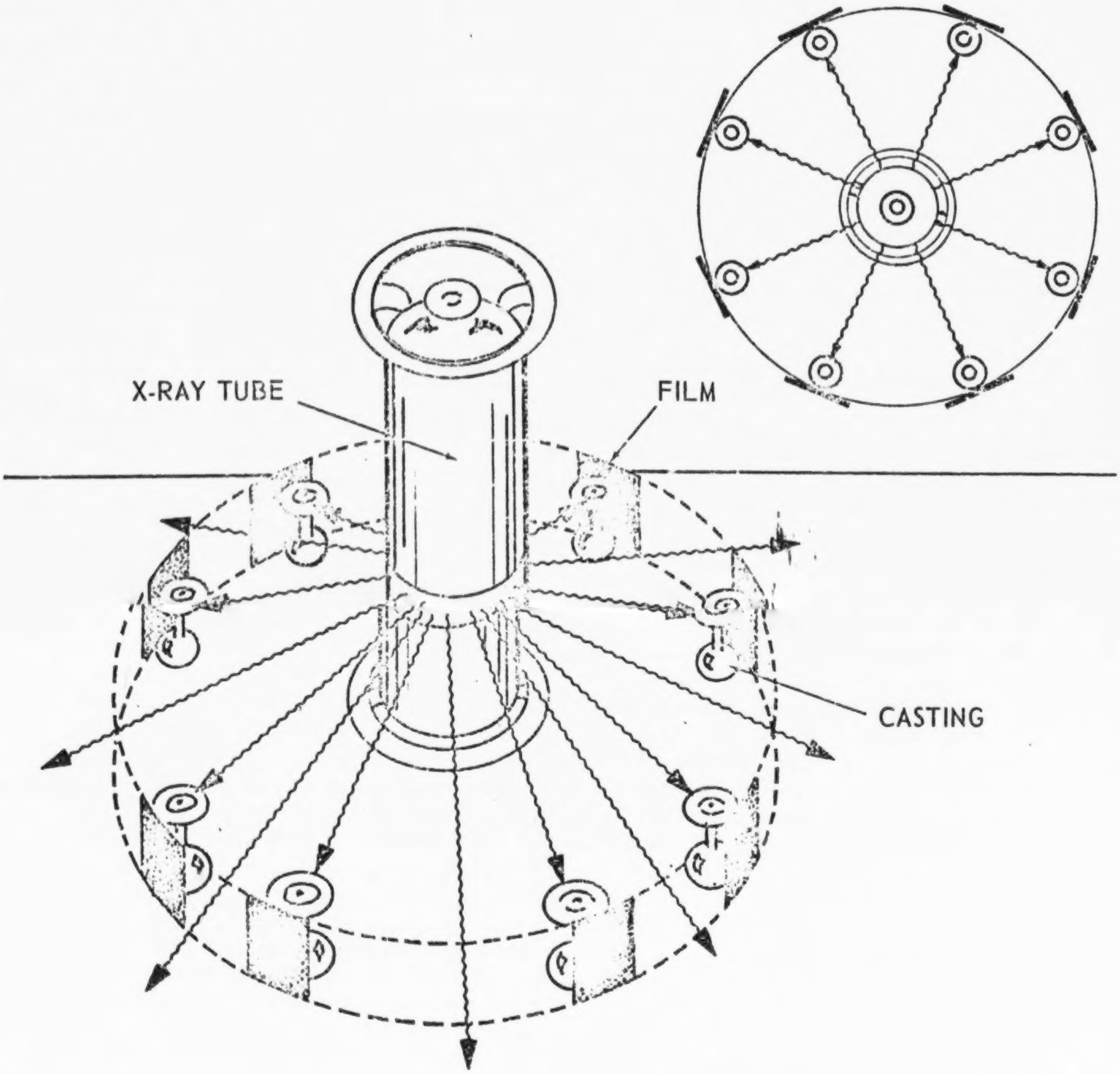
X-RAY TUBE
FILM
CASTING

Figure 9. Diagram of the Panoramic Radiographic Procedure.

(measured at one meter from the scatterer) is less than 0.1 percent of the incident exposure rate measured at the scattering object (38). This means that if the exposure rate in a collimated beam from a unit is 20 R/min at one meter from the X-ray tube, there would be an exposure rate of approximately 20 mR/min at 90° from the beam at a distance of one meter from the scattering object which is located one meter from the X-ray tube.

Many of these installations do not have a ceiling. The region over the enclosure is normally unoccupied and in addition, it may be necessary to lower objects into the enclosure for inspection. If there is no ceiling, two additional hazards exist: (1) the possibility of a crane operator remaining over the enclosed area during the exposure and (2) the problem of "skyshine." When large amounts of radiation, such as that associated with large X-ray machines, are produced in a room, "skyshine," or radiation scattered by the air or other material above the source of radiation, may create higher dose rates in areas away from the operational location than those present in adjacent areas.

In this type of installation, shielding is the primary method used for radiation control. Where occupancy is likely, the shielding is generally designed to reduce the radiation to acceptable levels. For accessible but normally unoccupied areas, the levels may be greater. Interlocks should be provided to prevent access to the room during an exposure. When an operator cannot see the entire room to make sure that no one is inside, warning devices are sometimes displayed in the room before exposure. If there is no way of turning off the X-ray machine from inside the room, fast, easy exit should be available.

Once adequate precautions are taken, such as providing interlocks and shielding, upkeep on these devices is needed to insure that safety is maintained. Insufficiencies may arise, however, even with good maintenance, if a new, more powerful unit is installed. A higher power X-ray machine might require additional shielding and if the beam is directed in a manner for which the shielding is inadequate, a hazardous situation may result.

Portable X-ray Installations. The most hazardous situation typically arises in the use of portable X-ray units. These units are normally designed to operate at low voltages (below 100 kVp, some with beryllium windows) and all the medium voltages up to and including 400 kVp. Since these units are brought to the work, permanently fixed radiation shielding cannot be used. Fluoroscopy, though seldom used in this type of arrangement, may be performed utilizing remote observation, such as closed circuit television.

Some portable units have their own battery pack power supplies which produce voltages up to about 120 kVp, and operate at tube currents up to 20 mA and exposure times as long as 12 seconds. Some of the X-ray tubes can be operated at peak voltages around 100 kVp and are small enough to be easily held in one hand (not a recommended procedure). Other tubes are water cooled to allow continuous operation for long periods of time.

Proper precautions are necessary to prevent entry in the area of radiation. For a low energy, portable machine operating at 150 kVp and 5 mA, radiation outputs in the beam can be in excess of 9.5 R/min at one meter from the X-ray tube. Thus, the potential for excessive exposures to people working near this type of installation is great. In the aircraft industry, for example, radiography often takes place in a hanger where other personnel are working at the same time. Many times, aircraft are inspected with X-rays outside on the parking strips where complete control is limited or difficult.

The method most often employed for preventing of limiting radiation exposures to workers not involved in the radiographic procedure is to erect a rope or other barricade at a reasonable distance from the X-ray unit, with warning signs which indicate the reason for the barricade. If possible, the unit should be operated at a time when the fewest personnel are in the area. Warning devices such as signs or flashing lights, proper monitoring, and the posting of a guard at the barricade to make sure that no one enters a high radiation area are thus the primary safeguards. For the radiation workers who perform the radiographic procedure, a common method for limiting exposure is to establish time limits for being in the radiation area.

Specialized Industrial X-ray Equipment

X-ray Gauges. All materials absorb X-rays to some extent and the amount of absorption is related to the material's thickness and density. This phenomenon is the principle of operation of X-ray gauges. There are two types in use, the thickness gauge and the density gauge. The thickness gauge is used for the continuous thickness measurement of materials such as sheet metal, glass, and rubber. The density gauge is used when the thickness of the material is constant and changes in density are indicated by the amount of X-rays absorbed. In general, when a radiation detector senses that a larger or smaller amount of X-rays is being transmitted through the material, an alarm or regulatory device will be actuated. Similarly, these devices may be used to indicate when the liquid in a container has reached a certain level. These devices are typically operated continuously for long periods without an operator and are usually designed to be used in areas where the employees are not classified as radiation workers. In general, these machines are in the low energy category and the potential exposure levels possible when the protective measures are removed are the same as those associated with comparable low energy radiographic units.

The protective measures required for this type of equipment are usually fairly simple. These units produce low exposure levels when in good condition and, further, can be situated in inaccessible areas of the production line where there is very limited occupancy. Maintenance should be done only when the unit is turned off. Shielding materials should be kept in good condition. Interlocks should be placed to prevent machine operation when the shielding is not in place. Frequent surveys of the unit should also be performed to confirm the normally low radiation levels associated with the unit.

Flash X-ray Units. A system called flash X-ray has been developed in recent years, and is now on the market. This system employs the field emission method of obtaining electrons at very high currents (on the order of thousands of amperes) without utilizing a heated filament as the source. With such large currents, which occur for a very short time, pulses of X-rays are produced for times on the order of nanoseconds and may have maximum instantaneous exposure rates in a 30 nanosecond pulse equivalent to 10^5 R/min at 40 inches from the target. These units are used in the same ways as the more conventional equipment. In addition, these units are capable of producing "stop-motion" radiographs of various sorts. Because of high exposure rates produced in very short pulses, the higher power units are capable of such techniques as radiography of a bullet as it is fired from the barrel of a pistol. The portable units have found application in the electric power industry in the inspection of insulators used on high tension power lines. The units are light and can be taken into the "cherry picker" with the inspector quite easily.

Since these units are used in much the same manner as conventional X-ray units, the hazards involved are similar to those found with conventional equipment used in similar situations. One disadvantage of the portable unit is that the small size suggests minimum nazards, which may foster disregard for the dangers involved.

Maintaining a safe distance from the tube and using proper shielding are the best methods for exposure control Surveying the situation before operating the unit, to determine where hazardous conditions exist, should be common parctice, particularly in field situations.

EXISTING GUIDANCE AND CONTROLS

The following sections describe the regulations, standards, and guides that govern the manufacture and use of particle accelerators, industrial radiographic and fluoroscopic units, and analytical X-ray equipment. The sections indicate where the guidance originates: (1) at the Federal level, (2) at the State level, (3) from quasi-regulatory organizations such as the American National Standards Institute, or (4) in the radiation safety information and services provided by the manufacturer.

Appendix A is an annotated bibliography of guidance from the first three sources listed above. For each item, the following information is given: Equipment to which it applies, title of the standard, type of standard, intended user, and a summary of the contents. The type of standard is denoted as Class A, Class B, or Class C, defined as follows (40):

Class A — A standard, code, criterion, specification, rule, performance requirement, procedure or method which is established or adopted by a governmental body acting under the authority of an act, law, or statute.

Class B — A standard, code, criterion, specification, rule, performance requirement, procedure or method that has been prepared and/or adopted by consensus of a committee(s) or commission(s) of technical competence in standards-setting organizations. The standard may be incorporated in whole or in part into a regulation. They may have restricted application depending upon the choice or obligation of individuals or users of the standard.

Class C — A guide, standard, code, criterion, specification, rule, performance requirement, procedure or method which has not yet been adopted by a standards-setting organization but contains information pertinent to the preparation of suitable standards or regulations.

Federal Control

There is only one Class A Federal regulation that pertains to the use of particle accelerators, industrial X-ray machines, and analytical X-ray equipment by organizations not within the Federal government. This regulation is the radiation standard published under 41 CFR Part 50-204 which expresses the Secretary of Labor's interpretation and application of the Walsh-Healey Public Contracts Act and which applies to contractors who have entered into contracts with an agency of the United States Government for the manufacture or furnishing of materials, supplies, articles, and equipment in any amount exceeding $10,000 (app. A, ref. A). The radiation standards promulgated thus far under this Act include only basic standards for protection against all types of ionizing radiation; no specific guidelines are given for particle accelerators or industrial X-ray machines.

There are three Class C Federal guidelines for particle accelerators; two of these pertain to Atomic Energy Commission installations (app A, ref. B and C) and the third is a list of recommendations published by the Public Health Service for all accelerator users and State radiological health personnel (app. A, ref. D). A similar list of radiation safety recommendations has been published by the Public Health Service for analytical X-ray equipment (app. A, ref. E).

State Control

Since the Atomic Energy Act of 1954, and the subsequent private development of atomic energy for peaceful purposes, the States have become increasingly aware of the many problems relating to the use of radioactive materials. As a result, the hazards of machine-produced radiation have also been brought to the attention of the States. Accordingly, the Council of State Governments, the AEC, and the PHS proposed model regulations. In 1964, the first version of the Suggested State Regulations for Control of Radiation was published (41). Presently the model regulations are undergoing revision in order to remain abreast of current needs for regulation and control of new products being developed and utilized. The model regulations have been fashioned as suggested legislative guidelines for implementation by each State as it may see fit. The regulations may be of assistance to States which desire to regulate all types of radiation sources.

Currently, many State regulations are patterned after the suggested model regulations, although some may differ slightly in certain aspects.

An analysis of the Council of State Governments' Suggested State Regulations for Control of Radiation reveals that control over such products as industrial X-ray machines and analytical X-ray devices may be derived from certain provisions within the regulations, in particular parts C and D.

Part C of the model regulations deals with the standards for protection against radiation. In particular, it discusses exposure of individuals to radiation in restricted areas. Moreover, the section deals with precautionary procedures, such as surveys and personnel monitoring, which may be applicable to facilities that utilize analytical X-ray devices and industrial X-ray machines.

Part D of the Suggested State Regulations for Control of Radiation discusses radiation safety requirements for industrial radiographic operations. Within this area are not only conventional industrial X-ray facilities but also those facilities which may utilize X-ray diffraction equipment, cabinet radiography, shielded room radiography, and field radiography. The section is not clear as to whether devices such as spectrographic X-ray units would be included; also, there is no mention of particle accelerators. Part D places limitations upon those people who are qualified to act as radiographers and radiographer's assistants. It also details operating and emergency procedures for the use of radiographic equipment, and discusses personnel monitoring control and precautionary procedures in radiographic operations. In the April 1966 Addendum to the Suggested State Regulations for Control of Radiation, part D has been enlarged to include special requirements for radiography employing radiation machines. In this section, certain provisions are set out which may exempt cabinet radiography, shielded room radiography, and field radiography from certain other requirements of part D.

Nowhere in the Suggested State Regulations for Control of Radiation are there any specific provisions for the regulation of particle accelerators. At present, only two States are considering adopting regulations specifically directed to particle accelerators. In addition, the Pennsylvania State Health Department has promulgated a "Radiation Safety Recommendation for Accelerators and Super-Voltage X-ray Users." No other State has provisions for regulation of such devices other than a general provision which might require registration of radiation sources.

In a recent survey of the 50 States plus Puerto Rico, Guam, the Virgin Islands, and the District of Columbia, it was found that 42 of the States (henceforth "States" will refer to the 50 States, plus Puerto Rico, Guam, the Virgin Islands, and the District of Columbia) have enforceable regulations for industrial X-ray and/or X-ray diffraction equipment. Of these 42 States, 36 have regulations which are substantially in agreement with the Suggested State Regulations for Control of Radiation in regard to industrial X-ray equipment. Thirty-seven of the 42 States have regulations which are also substantially in agreement with the Suggested State Regulations for Control of Radiation in regard to X-ray diffraction equipment. It was also found that 34 of the States have general provisions for regulation of accelerators, whereas 20 do not. However, it is important to remember in this context that, in some instances, regulations for accelerators merely require registration of the equipment.

More important than a State's written regulations are its actual radiation control activities. These activities may range from prelicensing and preregistration surveys of facilities through design approval to the routine safety evaluation of certain facilities.

Currently, only three of the 54 States routinely make prelicensing or preregistration surveys of nonmedical X-ray facilities. However, 32 of the 54 States will make a preregistration or prelicensing survey if they consider it necessary. Preregistration surveys of accelerator facilities are routine in nine States and an additional 26 States will make such preregistration surveys if they consider them necessary.

Another important aspect of the States' radiation control activities is the requirement that the radiation control agency be notified before new or remodeled facilities can become operational, and in some cases, that the agency approve design plans. Nineteen of the 54 States require accelerator facilities to provide such notification. Furthermore, 19 States require nonmedical X-ray facilities to provide such notification and 15 States require design approval for such nonmedical X-ray facilities.

Information regarding State surveys of accelerators and other nonmedical X-ray facilities is presented in Table 5. The degree of compliance to regulations is shown in Table 6.

Table 5. State surveys of accelerators and nonmedical X-ray facilities

Type of facility	Number licensed or registered	Number initially surveyed	Number resurveyed
Accelerator	409	261	156
Nonmedical X-ray radiographic	4,878	2,790	2,010
Other nonmedical X-ray	1,626	1,474	1,175

Table 6. Compliance of accelerator and other nonmedical X-ray facilities

Type of facility	Number surveyed 1966-1968	Number in compliance	Percentage in compliance
Accelerator	273	182	66.7
Nonmedical X-ray radiographic	2,426	1,620	66.8
Other nonmedical X-ray	857	714	83.3

Another important aspect of State radiation control is the requirement of certain States that operators of industrial X-radiography equipment and other nonmedical X-ray equipment be registered, licensed, certified, or have some X-ray training. No State requires either industrial X-ray radiography operators or other nonmedical X-ray operators to be licenses. Two States require industrial X-ray radiographers to be registeres; two States require other nonmedical X-ray operators to be registered; and one State requires certification of industrial X-ray radiographers. Twenty-two States require some form of X-ray training for industrial X-ray radiographers, and 14 States require certain X-ray training for other nonmedical X-ray operators.

It is apparent that some States do exercise some form of regulation over such devices as industrial X-ray machines, analytical X-ray devices, and particle accelerators; however, the form of regulation and control varies considerably from State to State. While most States have general regulations for industrial X-ray facilities and operators, there are practically no such regulations for particle accelerators and analytical X-ray devices. Moreover, those general regulations that are applicable to analytical X-ray devices lack effectiveness through their failure to recognize the subtle hazards which might arise from the use of analytical X-ray units. In other words, current control of such equipment appears to be too general and too inconsistent when the possible hazards are considered.

Quasi-Regulatory Guidelines

The term quasi-regulatory is used here to designate guidance originating from established organizations which have no regulatory authority but, because of their reputation and history of recognized excellence in their field, have a strong influence on the regulatory bodies. The organizations of this nature with recommendations pertaining to nonmedical X-ray devices are the American National Standards Institute (ANSI), the National Committee on Radiation Protection and Measurements (NCRP), the International Commission on Radiation Protection (ICRP), and the Council of State Governments.

The ANSI has only one published safety standard that indirectly applies to industrial X-ray machines, analytical X-ray devices, and particle accelerators (app. A, ref. F). This standard, NBS Handbook 93, presents brief but basic radiation protection recommendations for equipment, shielding, and safe operating procedures for nonmedical X-ray sources. It is applicable to accelerators when they are used as a source for nonmedical X-rays. As applicable to analytical X-ray equipment, it states that experimental diffraction apparatus may be regarded as an "open protective installation," but that "special protection requirements for such installations will be included in pending reports of other subcommittees." The section on Open Protective Installations lists four administrative requirements, but specifies no technical requirements. Handbook 93 has its most obvious applicability to situations where nonmedical radiographic and fluoroscopic machines are used and discusses many relevant safety procedures.

A proposed ANSI standard (app. A, ref. G) would be devoted to radiological safety in the design and operation of particle accelerators. However, as noted in appendix A, if the discussion of the types of accelerator radiations is excluded, only six of the 111 sections, or approximately 5 percent deal with accelerator design. The remaining 95 percent of the sections are use standards pertaining to shielding, operation of a radiation safety program, and other actions under the control of the accelerator user. This indicates the importance that the ANSI Committee has placed on use standards.

Each of the NCRP reports relating to accelerators deals with a limited but important part of the subject of accelerator safety. NBS Handbook 72 (app. A, ref. H) discusses neutron radiation dosimetry, Handbook 63 (app. A, ref. I) discusses protection against neutron radiation, Handbook 55 (app. A, ref. J) provides recommendations for the safe application of the high-energy radiations from betatrons and synchrotrons, and Handbook 97 (app. A, ref. K) discusses shielding for high-energy electron accelerators.

NCRP Report No. 33 (app. A, ref. L) presents recommendations for the medical X-ray use of accelerators but many of the recommendations could apply to nonmedical uses. It is worthwhile to note that it recommends checking and appropriately servicing all interlocks once every six months. It calls for the area surveillance to be done by a qualified expert who is able to make the necessary measurements, evaluate their significance and take corrective measures as called bor by the evaluation.

The ICRP has also promulgated certain recommendations which are applicable to nonmedical X-ray machines. In sections of the ICRP Report of Committee III, entitled "Protection Against X-rays Up to Energies of 3 MeV and Beta and Gamma-Rays from Sealed Sources" (app. A, ref. M), there are certain brief but basic recommendations for accelerators used for production of X-rays below energies of 3 MeV, and there are certain administrative and equipment performance criteria outlined for installations using analytical X-ray equipment. In addition, many of the report recommendations are applicable to nonmedical radiography and fluoroscopy. This ICRP report contains the philosophy for setting standards for equipment and the use of it. The report contains only recommendations: "It should be stressed that recommendations for installations and operation of X-ray equipment, or for dealing with radioactive materials, are not in themselves sufficient to guarantee adequate protection."

Another important quasi-regulatory control over nonmedical X-ray machines is the Suggested State Regulations for the Control of Radiation promulgated by the Council of State Governments (app. A, ref. N). Sections of these recommended regulations may apply directly or indirectly to the use of nonmedical radiographic and fluoroscopic equipment and analytical X-ray devices. Although some sections of the regulations may also be interpreted to apply to particle accelerators, there is no specific mention of particle accelerators.

Other quasi-regulatory guidelines are specifically aimed at the control of analytical X-ray equipment. Some merely discuss basic radiation protection considerations (app. A, ref. O and P), while others detail safety procedures related to the use of such devices (app. A, ref. Q, R, and S).

Manufacturers' Guidelines

Particle Accelerators. Information and instructions on accelerator radiation safety are provided to the user by the accelerator manufacturer at the time of purchase. In 1968, the Bureau of Radiological Health sent a letter to the major accelerator manufacturers in the United States, in which they were asked detailed questions concerning accelerator safety. A summary of all the replies to this inquiry, and to another inquiry in 1969 to several additional manufacturers, is as follows:

1. All manufacturers provide an operating and maintenance manual, which generally includes sections on health physics and safety procedures. Several manufacturers provide more detailed technical information in the form of a separate health physics manual, suggested accelerator layouts, shielding requirements, and/or National Bureau of Standards Handbooks. The quality and quantity of this guidance, however, varies greatly. In one instance, a manufacturer of sealed-tube neutron generators makes no mention of any radiation hazards in his instructions for starting up and operating the tube, and includes only the following statement on the last page of these instructions, "CAUTION — this tube contains 9.5 curie tritium. Users must be adequately protected against the neutron radiation and also against secondary γ radiation."

2. All manufacturers have their field engineers instruct the user in the operation and radiation safety considerations of the accelerator during installation and testing. Several manufacturers provide formal or informal classes for the user that include discussions of radiation safety.

3. Unless a separate contract is in force, most accelerator manufacturers do not design, build, or install safety interlock systems for the accelerator facility in which their machine is installed. In general, the customer is advised and expected to provide and install his own safety system, with design assistance sometimes provided by the manufacturer. Provisions are made by the manufacturer, however, to wire any

user safety interlocks into the accelerator control system. Several manufacturers advise the user of the effectiveness of safety interlock systems.

4. Statements provided to the buyer indicate the manufacturer assumes no liability for damage to the customer's personnel or property and the customer must assume complete responsibility for radiological health safeguards.

The specific questions that were presented to the accelerator manufacturers and the replies from them that lead to the conclusions noted above may be found in appendix B, part A. The accelerator manufacturers contacted were:

Acquidata Incorporated	Austin, Texas
Allis-Chalmers	Milwaukee, Wisc.
Amperex Electronic Corporation	Hickesville, N. Y.
Applied Control Company	Cedar Grove, N. J.
Applied Radiation	Walnut Creek, Calif.
Baird Atomic Incorporated	Cambridge, Mass.
Bechtel Corporation	San Francisco, Calif.
Charles Scientific	New York, N. Y.
The Cyclotron Corporation	Berkeley, Calif.
Elliott Electronic Tubes	London, England
Field Emission Corporation	McMinnville, Ore.
High Voltage Engineering Corporation	Burlington, Mass.
Kaman Nuclear	Colorado Springs, Colo.
Nuclear-Chicago Corporation	Des Plaines, Ill.
Nuclide Corporation	State College, Penn.
ORTEC, Incorporated	Oak Ridge, Tenn.
Physicon Corporation	Boston, Mass.
Physics International	San Leandro, Calif.
Radiation Dynamics Incorporated	Westbury, N. Y.
Texas Nuclear Corporation	Austin, Texas
Varian Associates	Palo Alto, Calif.

Industrial Radiographic and Fluoroscopic Equipment. To determine the magnitude and extent of use of radiation-producing equipment and the existing radiation safety usage guidelines provided by the manufacturer, a letter was sent to the major manufacturers of industrial radiographic and fluoroscopic equipment asking for this information. An example of this request may be found in appendix B, part B. The industrial X-ray equipment manufacturers contacted were as follows:

Automation Industries Incorporated	Danbury, Conn.
Balteau Electric Corporation	Stamford, Conn.
Bicron Electronics Company	Canaan, Conn.
Dunlee Corporation	Bellwood, Ill.

Eureka X-ray Tube Corporation	Chicago, Ill.
Field Emission Corporation	McMinnville, Ore.
General Electric Company	Milwaukee, Wisc.
Machlett Laboratories	Springdale, Conn.
Mitchell X-ray Products Company	Morristown, Penn.
Philips Electronic Instruments	Mount Vernon, N. Y.
Picker Corporation	White Plains, N. Y.
Siefert X-ray Corporation	King of Prussia, Penn.
TESCO	Natick, Mass.
Westinghouse Electric Corporation	Baltimore, Md.

A summary of the answers to this inquiry may be found in appendix B, part C. The answers ranged from "We have no written radiation safety guidelines" and "Customers are told to notify State or city industrial hygiene departments responsible in their locality," to answers which stated that they not only included National Bureau of Standards Handbook 93, but also had specific procedures and instructions included in the operating manuals. One company requires a signed statement from the customer that says he has installed the equipment properly and has read the warning notice that the unit produces hazardous radiation.

Another company suggests to the customer that he study the radiation protection information put out by the National Bureau of Standards. Two companies which manufacture X-ray machines that present special problems in radiation monitoring did not indicate that they presented any guidelines at all.

One company indicated that they operate on the assumption that any person authorized to use the equipment is aware of the dangers associated with the equipment. This is convenient thinking on the part of the manufacturer and places all responsibility for discovering the hazards on the user. Even if the customer was aware of the dangers but did not know how to cope with them, the equipment could be extremely hazardous to himself and to others around him. With the variety of X-ray equipment sold for industrial uses, it is important that the user know what the associated radiation problems are and that he be competent to handle these problems as they are presented.

Analytical X-ray Equipment. The following manufacturers were contacted by letter (app. B, part B) to determine if they manufacture analytical X-ray equipment and if so, what information and services they provide to the buyer regarding potential radiation hazards and recommended safety techniques.

Applied Research Laboratories	Sunland, Calif.
Beckman Instruments, Incorporated	Fullerton, Calif.
Cambridge Scientific Instruments, Ltd.	Cambridge, England
Consolidated Electrodynamics Corporation	Pasadena, Calif.
Dunlee Corporation	Bellwood, Ill.

Elliott Brothers Ltd.	London, England
Engis Equipment Company	Morton Grove, Ill.
Enraf-Nonius, Inc.	Garden City Park, N. Y.
Eureka X-ray Tube Corporation	Chicago, Ill.
General Electric Company	Milwaukee, Wisc.
Jarrell-Ash (Fisher Scientific Co.)	Waltham, Mass.
JEOLCO, Incorporated	Medford, Mass.
Machlett Laboratories	Springdale, Conn.
Materials Analysis Company	Palo Alto, Calif.
Philips Electronic Instruments	Mount Vernon, N. Y.
Picker X-ray Corporation	White Plains, N. Y.
Rigaku Denki Company	Tokyo, Japan
Siemens America, Incorporated	New York, N. Y.
Tem-Pres Research, Incorporated	State College, Penn.

The replies are summarized in appendix B, part D. Thirteen of the seventeen companies responding indicated that they supply their customers with some type of safety information and/or services. One company supplied only a brief paragraph on safety techniques. Several companies supplied the customer with booklets or articles on radiation safety and some included lengthy safety instructions in either their operating manuals or in a "Warning Notice." Also, some manufacturers provide radiation warning signs which may be placed by the user. It is the polich of another company to require a statement signed by the customer in which he states that he has read a warning notice (which has been previously mailed to him) and agrees to install equipment accirding to instructions provided in this notice. No other companies make such requirements of a potential customer.

Radiation safety services varied considerably from company to company. Service engineers for one manufacturer are provided with radiation survey meters for use during servicing of equipment. Another manufacturer offers to assist the customer in placing his equipment in use. However, most manufacturers did not openly offer their customers consultation or other services regarding the safety of equipment as it is to be used in that particular installation.

ACCIDENTS INVOLVING NONMEDICAL IONIZING RADIATION-PRODUCING EQUIPMENT

Stimulated by the advances of modern technology, the use of nonmedical electronic products which generate ionizing radiation have significantly increased and have become widely diversified. Inherent with this progress has been an increased potential for radiation exposure, primarily to the radiation worker. The situation may be compared to that of the use of radioisotopes, which over recent years has markedly grown and which has consequently exposed more workers to the associated radiation hazards. As the utilization of such products increases, so does the probability of radiation incidents.

A compilation of such incidents involving nonmedical ionizing radiation-producing equipment which have resulted in exposures or suspected exposures to individuals may be found in appendix C. In some instances, the exact causes of the accidents are not readily determinable, nor even inferrable. However, the most common causes of the incidents may be calssified into three general categories, one being negligence on the part of the operator, another being equipment failure, and a third category being negligence on the part of the manufacturer.

Machines that are designed to produce ionizing radiation must be regarded as dangerous instrumentalities. It has been held by the courts that "a supplier of a dangerous instrumentality is under a legal duty to warn prospective users of dangers of which it is aware, or of which it should be aware and that such warning should be commensurate with the danger involved; i.e., warnings must be directed to a specific danger and must be sufficient to cause a reasonable man acting under similar circumstances with the same knowledge and background to know the potential danger involved in the exercise of reasonable care" (42).

However, even when sufficient warnings are present, there still persists a certain degree of probability that the operator may act negligently. Such negligent actions may vary from an unreasonable disrespect of the dangers of exposure to harmful radiation (such as placing a hand in the path of a primary radiation beam thinking one can't be seriously injured), to a direct intentional violation of the specific functioning of safety devices (such as bypassing of interlocks, warning signals, and so forth).

In some instances, however, certain mechanical and/or electrical failures of a machine or its safety devices without fault of the operator have resulted in exposures.

It is evident from the description of the incidents in appendix C that serious injuries may result from careless and accidental misuse of such equipment as analytical and spectrigraphic X-ray devices, particle accelerators, and industrial radiographic X-ray machines.

The majority of the accidental exposures resulted from negligent acts of the operators. In most cases these could have been prevented by the procedural controls on not only the machine operators but also for any personnel who might be subject to exposure at the time of operation of the equipment. While in most instances the machines themselves are not designed with a certain degree of inherent safety, this is not to preclude the occurence of mechanical failures which may result in severe radiation exposures. Had fundamental safety procedures been utilized in the circumstances of some of the aforementioned situations, it would be reasonable to speculate that a majority of the incidents could have been prevented.

THE NEED FOR CONTROLS

One problem associated with the use of all three types of equipment described in this report is that of measuring the radiation. In selecting the best instrument for the measurement of radiation for a particular radiation monitoring problem, the convenience of operation, portability, reliability, economy, type of radiation, energy, and exposure rate dependence of the instrument must be considered. Each radiation monitoring task has its own individual set of considerations and it is necessary to know the characteristics and limitations of any survey instrument or pocket dosimeter in order to use it intelligently. Radiation detection instruments are limited to measuring certain types of radiation within a fixed range of energies. For other types of radiation or at certain energies of radiations, their readings may not only be useless, but often misleading. It is extremely important that survey and monitoring instruments be properly maintained and calibrated and sensitive to those radiations being monitored.

Particle Accelerators

Particle accelerators are machines designed to produce radiation. Nonmedical uses include industrial radiography, activation analysis, radiation processing, and nuclear research. The type and magnitude of the radiation hazards vary according to the type of accelerator, the particles accelerated, the energy and beam current of the accelerated particles, and the use of the beam. The user purchases the accelerator from the manufacturer and installs it in his own installation. Consequently, facility shielding, safety interlocks, and warning devices may not be a part of the basic purchase and the quality of such associated equipment may vary widely depending upon the user's knowledge of radiation safety or the advice that he receives from knowledgeable consultants in the field. Additionally, since accelerators are usually installed in a room used only for that purpose, from a radiation safety viewpoint the requirements of the facility often can be more important than the inherent safety features of the accelerator itself.

As an example of the conditions that exist today with regard to accelerator safety, the following results of a survey of 27 accelerator facilities revealed that there is considerable room for the strengthening of existing accelerator radiation safety programs (43).

1. Of all the facilities surveyed, the worst conditions were found with an industrial betatron user where the safety program was limited to on-the-job training of operators, interlocked entrances, and physical inspection of the facility prior to startup. Lacking were adequate radiation surveys, personnel monitoring, maintenance of safety devices, an independent radiation monitoring system, warning lights, knowledge of the circuits of the interlock system, a means to secure the facility against unauthorized use, and a safety committee to review operations.

2. Of the industrial users whose machines were used for quality control purposes, none had an administrative review mechanism for the radiation safety problems.

3. Three-quarters of the facilities provided written operating procedures for operators but any actual use was doubted in at least 46 percent of these facilities.

4. Not all facilities utilized safety features such as an on-off key, prestart clearing sweep of high radiation areas, regularly scheduled maintenance of safety systems, interlocks for entrances to high radiation areas, surveys, and personnel monitoring. Interlock bypassing, a condition requiring close user supervision, was necessary at 52 percent of the facilities.

5. Less than half of the accelerator installations provided prestart alarms, warning lights, inside scram switches, and remote area monitoring systems. Few facilities provided an up-to-date circuit diagram of its safety systems.

6. It was the impression of the surveyors that the potential did exist for a repetition of the serious accelerator accident that occurred in October 1967. It existed at each facility where the human element was given less attention than the mechanical safety devices.

The NCRP and ANSI have reports that deal indirectly or apply only to a limited part of the entire subject of accelerator radiation safety. From a review of the accelerator accidents, it has been observed that the majority of them could not have been prevented by equipment design, but adherence to safety procedures would have done so. For example, one of the accidents indicated that "personnel engaged in the use of such equipment are now routinely cautioned to always check a potential source of radiation with an instrument and never assume that it is safe." While personnel at the facility where the accident occurred will undoubtedly remember this requirement, no assurances can be given that this recommendation will be provided to other accelerator facilities.

It is the conclusion of this study, therefore, that standards including instrumentation for the safe use of accelerators are needed. Such instructions should cover facility shielding, safety interlocks, personnel and area radiation monitoring, warning devices, radiation safety related operating procedures, and operator training requirements.

Analytical X-ray Equipment

Lubenau, et al report that since 1946, 22 individuals in Pennsylvania were overexposed to radiation in 17 accidents from analytical X-ray equipment to the extent that medical attention was required (44). Carelessness was the designated cause of accident in eight cases, inadequate instruction the cause in four cases, and equipment failure (defective shutters) the cause in five cases. A 1966 survey in Pennsylvania indicated that there were many unsafe conditions existing in analytical X-ray facilities and that many of these conditions were related to the manner in which the machine is used. Appendix C, part C of the study briefly described 16 accidents involving analytical X-ray equipment and it is easily seen that the majority of these occurred as a result of operator error rather than machine failure (in some situations, well planned machine design can reduce the possibility of operator error). Information collected by Lindell (30) on a worldwide basis indicated that a major risk of severe injury exists when machine operators attempt maintenance operations without first determining that X-rays are not emanating from the tube. Remedial measures suggested by Lindell are:

1. "Adequate instruction to the staff and maintenance personnel, including warning signs at or on the units," and

2. "Simple and fail-safe methods of ensuring that the tube is not 'on' when any repair or alteration is undertaken."

Lindell further notes that, from preliminary data, "equipment as used in normal operations appears to be perhaps safer than one might have expected, and that equipment failure has not been found to be a cause of severe accidents." Thus, it appears that operator education and safety controls over operating or use procedures, especially those of a nonroutine nature, would reduce the number of overexposures in which medical attention is required.

Existing voluntary standards and guides cover both the use and design of analytical X-ray equipment, but comprehensive regulations for the control of the hazards associated with the use of this equipment have not been promulgated.

Most State public health agencies have the authority to regulate the use of analytical X-ray equipment, but, with several notable exceptions, few States have taken an active role in this area.

It appears that standards which are provided for in the "Radiation Control for Health and Safety Act of 1968" will prove valuable in reducing chronic radiation exposure and some severe overexposures. However, it is the conclusion of this study that a radiation safety performance standard for analytical X-ray equipment must include instructions regarding operator training, repairman training, permissible radiation levels, personnel and area monitoring, mixing of components built by different manufacturers, and safety features involving the facility itself (for example, door locks, warning signs, shielding, and so forth).

Industrial Radiographic and Fluoroscopic Equipment

There is no one standard or set of recommendations that adequately gives guidance to the users of industrial X-ray equipment. The guidelines, when offered to the purchaser by the manufacturers, are generally inadequate to describe the hazards. By taking the best from each of the standards and recommendations and from some of the manufacturers guidelines, a fairly good set of recommendations can be collated. The ICRP publication is good for setting the background philosophy for radiation protection; however, philosophy does not present specific enough procedures to be followed and this is why standards are needed.

Many of the States have taken the "Suggested State Regulations for Control of Radiation" by the Council of State Governments and have almost written these recommendations into their regulations. While the recommendations are adequate, they could be improved especially in the parts that apply to the user. By strengthening the regulations and making people aware of the hazards involved, the exposure to the population could be reduced. This has far reaching significance in the light of the well established genetic problems associated with exposure to radiation. It is because of these problems that there exists a need for standards for the use of nonmedical X-ray equipment.

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APPENDIX A

ANNOTATED BIBLIOGRAPHY OF EXISTING GUIDANCE AND CONTROLS

Appendix A

ANNOTATED BIBLIOGRAPHY OF EXISTING GUIDANCE AND CONTROLS

The references in this annotated bibliography are referred to in Section 5 of this report. The type of standard is classified as either Class A, Class B, or Class C (40) as follows:

Class A - A standard, code, criterion, specification, rule, performance requirement, procedure, or method which is established or adopted by a governmental body acting under the authority of an act, law, or statute.

Class B - A standard, code, criterion, specification, rule, performance requirement, procedure, or method that has been prepared and/or adopted by consensus of a committee(s) or commission(s) of technical competence in standards-setting organizations. The standard may be incorporated in whole or in part into a regulation. They may have restricted application depending upon the choice or obligation of individuals or users of the standard.

Class C - A guide, standard, code, criterion, specification, rule, performance requirement, procedure, or method which has not yet been adopted by a standards-setting organization but contains information pertinent to the preparation of suitable standards or regulations.

REFERENCE A

Applies to: All Types of Ionizing Radiation Equipment

Title: Code of Federal Regulations Title 41, Part 50-204, Safety and Health Standards for Federal Supply Contracts
Federal Register, Volume 34, No. 12, January 17, 1969

Type: Class A - Rules and Regulations

Intended For: Contractors who have entered into contracts with an agency of the United States for the manufacture or furnishing of materials, supplies, articles, and equipment in any amount exceeding $10,000.

Contents: This Part 50-204 expresses the Secretary of Labor's interpretation and application of the Walsh-Healey Public Contracts Act with regards to certain particular working conditions and requirements concerning the instruction of personnel, notification of incidents, reports of exposures, and maintenance and disclosure of records. The Safety and Health Standards include the following:

General Safety and Health Standards
- Material Handling and Storage
- Tools and Equipment
- Machine Guarding
- Medical Services and First Aid
- Personal Protective Equipment
- Use of Compressed Air
- Occupational Noise Exposure

Radiation Standards
- Exposure of Individuals to Radiation in Restricted Areas
- Exposure to Airborne Radioactive Material
- Precautionary Procedures and Personnel Monitoring
- Caution Signs, Labels, and Signals
- Storage of Radioactive Materials
- Waste Disposal
- Notification of Incidents
- Records
- Radiation Standards for Mining

Gases, Vapors, Fumes, Dusts, and Mists
- Inspection of Compressed Gas Cylinders
- Safety Relief Devices for Compressed Gas Cylinders

Transportation Safety

The radiation standards set forth in this 41 CFR Part 50, are essentially the same as 10 CFR Part 20, which is the Atomic Energy Commission rules and regulations on Standards for Protection Against Radiation. Instead of only applying to by-product material, however, 41 CFR Part 50 applies to all types of radiation which includes X-rays and neutrons. Within the standards, however, there are no specific guidelines given for industrial X-rays, particle accelerators, or analytical X-ray equipment.

REFERENCE B

Applies To: Particle Accelerators

Title: Safety Guidelines for High Energy Accelerator Facilities
National Accelerator Safety Committee
U.S. Atomic Energy Commission, TID 23992, 1967.

Type: Class C - Committee of AEC personnel

Intended For: AEC supported accelerator laboratories

Contents: The report is intended to assist each AEC laboratory in developing and evaluating its requirements for a comprehensive safety program. The Committee was established to prepare the report after a major fire and explosion at an AEC High Energy Physics installation on July 5, 1965. The guide provides a summary of the best safety knowledge and experience currently available on accelerator laboratories and the guidelines are purposely broad to allow adequate latitude for each laboratory to develop or modify its detailed safety programs. Radiation protection and electrical safety guidelines are treated only in a peripheral manner. Topics covered include:

- Management Safety Guidelines
  - Responsibility and Delegation of Authority
  - Review Procedures
  - Issuance of Safety Manuals
  - Emergency Procedures
- Building and Facilities Guidelines
  - Design of Building Structure
  - Exhausting or Venting of Hazardous Gases
  - Grounding and Lightning Protection
  - Storage of Hazardous Materials
- Experimental Equipment
  - Guidelines for Nonflammable Noncryogenic Systems
  - Guidelines for Nonflammable Cryogenic Systems
  - Guidelines for Flammable Noncryogenic Systems
  - Flammable - Cryogenic Systems
- Operating Procedures
  - Procedural Requirements for Experimental Operators
  - Operating Procedures for Specific Equipment
  - Emergency Procedures in the Event of Equipment Failure
  - Experimental - Area management

REFERENCE C

Applies To: Particle Accelerators

Title: Safety Guidelines for Accelerator Installations
Hernandez, H. Paul, Lawrence Radiation Laboratory, University of California, Berkeley, California,
UCRL Report 18555

Type: Class C - Guide suggested by Author

Intended For: Atomic Energy Commission accelerator installations

Contents: This report begins by summarizing the two AEC reports containing safety guidelines. These are "Safety Guidelines for High Energy Accelerator Facilities," described elsewhere in this summary of accelerator standards, and "Electrical Safety Guides for Research," which provides electrical safety advise to AEC research laboratories. The first report treats radiation safety only in a peripheral manner and the second report on electrical hazards is not a topic of this particular study. UCRL 18555 continues with a discussion of hazard identification, building forced air emergency ventilation, water sprinkler systems, spark induced explosions in hydrogen purifiers or liquefiers, and other nonradiation considerations. It does not discuss at all the radiation safety considerations for accelerators and has very little applicability to the low to moderate energy accelerators.

REFERENCE D

Applies To: Particle Accelerators

Title: Recommendations for the Safe Operation of Particle Accelerators
Gundaker, W. E. and Boggs, R. F.
Bureau of Radiological Health, MORP Report 68-2, February 1968

Type: Class C - Recommendations Suggested by Authors

Intended For: Accelerator Users and State Radiological Health Personnel

Contents: The recommendations are considered the minimum safety procedures for accelerator facilities. They are intended to supplement existing regulations or standards and to emphasize the more important items in an accelerator radiation safety program. The recommendations as published were prepared following a review of draft lists by Bureau of Radiological Health personnel, State health departments, other radiological health personnel, and accelerator users. They are short, concise statements covering the following topics:

Administration and Personnel
Accelerator controls
Interlock Systems
Warning Devices
Radiation Monitoring
Radiation Protection Survey

An appendix summarizing 12 published accelerator accidents involving radiation exposure is included also.

REFERENCE E

Applies To: Analytical X-ray Equipment

Title: Radiation Safety Recommendations for X-ray Diffraction and Spectrographic Equipment
Moore, Thomas M. and McDonald, Donald J.
Bureau of Radiological Health, MORP Report 68-14, October 1968

Type: Class C - Recommendations suggested by authors

Intended For: Operators, administrators, manufacturers, and State radiological health personnel, who are concerned with the design and operation of X-ray diffraction and spectrographic equipment.

Contents: This document was reviewed by State health personnel, manufacturers, and users of this equipment. It contains 30 recommendations covering the following topics:

Administrative Responsibilities
Operating Procedures
Personnel Monitoring
Area Monitoring
Safety Engineering
Special Requirements for Research Installations

REFERENCE F

Applies TO: Particle accelerators, Industrial Radiographic and Fluoroscopic Equipment, Analytical X-ray Equipment

Title: Safety Standard for Nonmedical X-ray and Sealed Gamma-Ray Sources, Part I, General
National Bureau of Standards Handbook 93, January 3, 1964 by Subcommittee I, General Provisions and Materials Protection, of the ASA Z54 Sectional Committee (ASA designation Z54.1-1963, UDC 614.898:537.531)

Type: Class B - Standard of the American Standards Association (now the USASI)

Intended For: Nonmedical X-ray equipment users

Contents: This Handbook is intended to serve as a guide toward the safe use of X-ray and sealed gamma ray sources for nonmedical purposes and of equipment emitting X-rays serving no useful purpose. The Handbook presents basic radiation protection recommendations through the use of appropriate equipment, ample structural shielding, and most important, safe operating procedures. The contents include:

Classification of protective installations
  Exempt protective installation
  Enclosed protective installation
  Open protective installation

Selection of class of protective installation

Plans for radiation installations
  Review by qualified expert
  Effect of distance on shielding requirements
  Direction of use
  Multiple sources of radiation
  Radiation energy, output, and workload
  Shielding for films and low level counting rooms
  Shielding for films and low level counting rooms

Structural details of protective barriers
  Quality of protective material
  Lead barriers
  Shielding for openings in protective barriers

Radiation protection survey
    Survey of new installations
    Changes in existing installations
    Report of radiation protection survey
    Radiation protection survey procedures

Operating procedures
    Restrictions according to classification
    Control of personnel
    Radiation safety instructions
    Personnel monitoring

The standards set forth in this Handbook apply to particle accelerators, when used as a source of nonmedical X-rays, nonmedical X-ray machines, and analytical X-ray devices. The important sections of the Handbook, however, are extremely brief. Of the total 60 pages, only 11 pages cover safety standards and 4 of these discuss the classification of protective installations. This leaves very little to cover a broad subject of radiation protection surveys, operating procedures, and structural details of protective barriers.

REFERENCE G

Applies To: Particle Accelerators

Title: Radiological Safety in the Design and Operation of Particle Accelerators Proposed USA Standard, United States of America Standards Institute, Submitted to USASI Committee N-43, April 1969.

Type: Class B - Proposed Standard

Intended For: Manufacturers and Users of Particle Accelerators

Contents: The proposed standard recognizes that basic design and operational requirements are inseparable elements of safety and provides guidance in the basic considerations essential to the safe operation of a particle accelerator. The standard applies to particle accelerators principally with primary energies less than 100 MeV. It considers the characteristics of and controls for radiation as they affect accelerator design, operating procedures and exposure evaluation. The topics covered include:

Radiation Protection Design Criteria
    Radiation Shielding Considerations
    Radiation Damage
    Safety Systems
    Accelerator Controls
    Electrical Interlocks
    Warning Devices

Operational Health Physics
    Radiation Safety Organization and Responsibility
    Radiation Safety Procedures
    Personnel Monitoring Requirements
    Area Monitoring Requirements
    Education and Training
    Record Keeping

Radiation Measurements
    Type of Radiations
    Instrumentation and Radiation Measurements
    Airborne Radioactivity Monitoring
    Test, Calibration and Maintenance

Dose Assessment
    Basic Exposure Considerations
    Maximum Permissible Dose
    Methods
    Dose Restrictions

In general, the proposed standards are short, concise statements indicating design features or operational steps that should be considered at an accelerator facility. Excluding a discussion of the types of accelerator radiations, of the 111 sections, only 6 or approximately 5% deal with design of the accelerator; the remaining 95% pertain to shielding, operation of a radiation safety program, and other actions under the control of the accelerator user.

REFERENCE H

Applies To: Particle Accelerators

Title: Measurement of Neutron Flux and Spectra for Physical and Biological Applications
Recommendations of the National Committee on Radiation Protection and Measurements
National Bureau of Standards Handbook 72, July 15, 1960

Type: Class B - Recommendations of the NCRP

Intended For: Persons performing neutron radiation dosimetry which includes accelerator users.

Contents: The measurement of neutron flux and spectra is discussed, various methods are compared, and results of intercomparisons are given. Methods of measurement are discussed for the emission rate of radioactive neutron sources, thermal neutron flux, intermediate neutron flux, fast neutron flux, and neutron energy spectra. Neutron radiation instruments for area survey and personnel monitoring involving flux and spectra measurements are included. Typical spectra of various neutron sources are shown.

This Handbook provides a detailed discussion of one of the many problems that an accelerator user may be confronted with.

REFERENCE I

Applies To: Particle Accelerators

Title: Protection Against Neutron Radiation Up to 30 million Electron Volts
Recommendations of the National Committee on Radiation Protection and Measurements
National Bureau of Standards Handbook 63, November 22, 1957, Reprinted with corrections April 1967

Type: Class B - Recommendations of the NCRP

Intended For: Persons concerned with neutrons as a special type of radiation hazard which must include accelerator users.

Contents: Recommendations are provided on the physical properties and biological affects of neutrons. The scope of the handbook covers many neutron sources and extends to neutron energies up to 30 MeV. The topics covered include:

- Present status of physical and biological information
  - Classification of neutrons and primary modes of interaction
  - Absorbed dose
  - Interactions between neutrons and tissue
  - Biological effects
  - Permissible exposure to neutrons
  - Neutron detectors
  - Measurement of neutron flux
  - Dose Measurement

- Radiation protection in installation and operation of neutron sources
  - Types of sources
  - Neutron production
  - Other radiation hazards associated with neutron production
  - Radiation protection considerations in the design of neutron sources
  - Stationary shields
  - Movable shields
  - Unusual hazards
  - Procedures to be implemented in case of overexposure

- Rules for protection against neutron radiation
  - Maximum permissible dose
  - Radiation protection officer
  - Radioactive sources
  - Accelerators
  - Reactors
  - Surveys at accelerators and reactors
  - Health
  - Overexposure

REFERENCE J

Applies To: Particle Accelerators

Title: Protection Against Betatron-Synchrotron Radiations Up
to 100 Million Electron Volts
Recommendations of the National Committee on Radiation Protection
National Bureau of Standards Handbook 55, February 26, 1954

Type: Class B - Recommendations of the NCRP

Intended For: Accelerator Users

Contents: Recommendations are provided for the safe application of the high-energy radiations from betatrons and synchrotons. The hazards resulting from the various radiations produced by these two types of electron accelerators are included, as well as those due to certain associated effects, such as noise, electricity, and ozone production. The recommendations are short, concise statements of good practice using the "shall" and "should" concept ("shall" indicates necessity in order to meet currently accepted standards of protection and "should" indicates advisory requirements that are to be applied when possible). The topics covered include:

- Protection Against Operation Hazards
  - Electrical Protection
  - Warning and Safety Devices
  - Operational Precautions
  - First Aid and Fire Protection
  - Inspection and Preventive Maintenance

- Protection Against Radiation Hazards
  - Units of Measurement
  - Methods of Measurement
  - Methods of Protection

- Installations
  - Structural Details
  - Layout Plans
  - Special Requirements for Medical Installations
  - Special Requirements for Industrial Installations
  - Special Requirements for Research Installations

- Surveys
  - Responsibility and Time of Survey
  - Radiations to be Measured
  - Survey Procedure

- Working Conditions
  - Responsibility
  - Personnel Monitoring
  - Health

REFERENCE K

Applies To: Particle Accelerators

Title: Shielding For High-Energy Electron Accelerator Installations
Recommendations of the National Committee on Radiation Protection and Measurements, NCRP Report No. 31
National Bureau of Standards Handbook 97, July 1, 1964

Type: Class B - Recommendations of the NCRP

Intended For: Accelerator Users and Facility Designers

Contents: The report is "intended to give a summary of the presently available data required to calculate the shielding for high energy, high intensity electron accelerator installations." It deals with electrons ranging in energy between 0.5 MeV and 100 MeV and with beam powers up to 100 kilowatts. "The report is not intended to present specific, all inclusive recommendations since it is not felt that at the present time the 'state of the art' has progressed to the point where such recommendations are feasible." The topics covered include:

Procedure for Determining Shielding Requirements

Beam Characteristics and Yields
- Electrons
- Bremsstrahlung
- Neutrons
- Residual Radioactivities

Radiation Measurements
- Units
- Surveying and Monitoring

Interaction of Radiation With Matter

This report presents a discussion of the considerations for electron accelerator shielding and presupposes that the reader will have a substantial knowledge of the field of high-energy physics.

REFERENCE L

Applies To: Particle Accelerators

Title: Medical X-ray and Gamma Ray Protection for Energies Up To 10 MeV - Equipment Design and Use
Recommendations of the National Council on Radiation Protection and Measurements
NCRP Report No. 33, February 1, 1968

Type: Class B - Recommendations of the NCRP

Intended For: Designers and Users of Medical X-ray and Gamma Ray eouipment

Contents: This report is concerned with protection against radiation emitted by medical X-ray equipment operating at energies up to 10 MeV and medical gamma beam therapy equipment. It presents recommendations pertaining to equipment design, use operating conditions, and to radiation protection surveys and personnel monitoring. The report includes sections for the specific guidance of (1) the physician and his associates, (2) the equipment designer and manufacturer, (3) the radiological physicist concerned with calibration procedures, equipment performance, and protection surveys, and (4) the radiological health inspector concerned with equipment inspection and survey measurements. The topics covered include:

General Considerations
    Fundamental Objective
    Maximum Permissible Dose Equivalent
    Exposure of Individuals
    General Guidelines in the Clinical Use of Radiation

X-ray Equipment
    Fluoroscopic Equipment
    Fixed Radiographic Equipment
    Mobile Radiographic Equipment
    X-ray Therapy Equipment

Gamma-Beam Therapy Equipment

Therapy Equiment Calibration Guides
    General
    Calibration
    Recalibration
    Spot Check Measurement

Radiation Protection Surveys

Working Conditions
    General
    Radiation Protection Supervisor
    Personnel Monitoring
    Medical Examination
    Vacations

While this report presents recommendations for the medical use of X-ray equipment and particle accelerators (X-ray therapy eouipment), many of the recommendations could apply to other nonmedical uses of these machines.

REFERENCE M

Applies To: Particle Accelerators, Industrial Radiographic and Fluoroscopic Equipment, Analytical X-ray Equipment

Title: Protection Against X-rays Up to Energies of 3 MeV and Beta and Gamma-Rays from Sealed Sources
Recommendations of the International Commission on Radiation Protection Report of Committee 3, ICRP Publication 3, 1960

Type: Class B - Recommendations of the ICRP

Intended For: National committees of radiation protection

Contents: In this report, which is based upon the codes of practice and operations in various countries, the main emphasis has, in accordance with the ICRP's policy, been placed on the basic requirements of radiation protection, leaving the expansion of detail technical requirements to National committees. The report indicates the requirements necessary for ensuring adequate protection and the various uses of the radiation to which it relates. It includes sections on

Plans for Installations Using X-rays and Sealed Gamma-ray Sources

Survey and Monitoring of Installations Using X-ray and Sealed Gamma-ray Sources

Recommendations on Equipment and Operating Conditions
- X-ray Medical Diagnostic Installations
- X-ray Therapeutic Installations
- X-ray Installations for Nonmedical Radiography and Fluoroscopy
- Installations for X-ray Analysis
- Miscellaneous Nonmedical Uses of X-rays
- X-radiation Emitted as an Unwanted By-Product
- Sealed Beta-and Gamma-ray Sources for Medical and Nonmedical Use

Protection of the Patient

If a particle accelerator is used for the production of X-rays below energies of 3 MeV, the brief but basic recommendations of the ICRP under the sections X-ray Installations for Nonmedical Radiography and Fluoroscopy would apply. The recommendations of the ICRP have in general been the guiding philosophy for standard settings organizations and government agencies here within the United States.

REFERENCE N

Applies To: All Types of Ionizing Radiation Equipment

Title: Suggested State Regulations for Control of Radiation
The Council of State Governments, Chicago, Illinois, April 1966

Type: Class B - Suggested State Regulations

Intended For: State officials (in drawing up State radiation control programs)

Contents: These recommended regulations provide for regulation of all sources of radiation in that they are not only designed to incorporate provisions necessary to qualify a State to assume certain of the regulatory responsibilities of the Atomic Energy Commission pursuant to Public Law 86-373, but also to provide for regulation of sources of radiation over which there has never been Federal jurisdiction. The recommendations are prepared by the Council of State Governments, the Atomic Energy Commission, and the Public Health Service. The regulations are modeled after applicable AEC regulations as they appear in Title 10 of the Code of Federal Regulations which, while they do not directly apply to X-ray equipment or particle accelerators, they do provide basic standards for protection against radiation. In addition, the regulations are modeled after recommendations of the National Committee on Radiation Protection and Measurements as embodied in NBS Handbook 73 and Handbook 76. The suggested State regulations cover the following topics:

General Provisions

Licensing and Registration
- Exemptions
- Licenses
- Specific Licenses
- Registration
- Records, Inspections, and Tests
- Reciprocity
- Transportation

Standards for Protection Against Radiation
- Permissible Doses, Levels, and Concentrations
- Precautionary Procedures
- Waste Disposal
- Records, Reports, and Notification

Radiation Safety Requirements for Industrial Radiographic Operations
- Definitions
- Equipment Control
- Personal Radiation Safety Requirements for Radiographers and Radiographers' Assistants
- Precautionary Procedures in Radiographic Operations

Use of X-rays in the Healing Arts

Use of Sealed Radioactive Sources in the Healing Arts

REFERENCE O

Applies To: Analytical X-ray Equipment

Title: International Tables for X-ray
Crystallography, Vol. III, Section 6 (1962).

Type: Class C - Unauthored guidance

Intended For: Administrators and users of X-ray, electron, and neutron diffraction apparatus

Contents: The text of this document mainly consists of a general discussion of radiation protection practices and does not cover details specific to a particular type of apparatus. Much of it is taken from the recommendations of the International Commission on Radiological Protection. Topics discussed are:

Objectives of Radiation Protection
Responsibility
Maximum Permissible Doses
Health Surveillance (pre-employment medical examination)
Personnel Monitoring

REFERENCE P

Applies To: Analytical X-ray Equipment

Title: Manual of Industrial Radiation Protection
Part II, Model Code of Safety Regulations (Ionising Radiations),
International Labor Office (1959).

Type: Class B - Recommendations of an International Labor Office technical conference.

Intended For: Governments and industry for use in framing or revising safety regulations.

Contents: This Code was intended to apply to sealed and unsealed radioactive substances as well as equipment capable of producing ionizing radiation. In addition to a number of general provisions relating to all processes involving a radiation hazard, there are special provisions which, among other things, discuss X-ray diffraction and similar uses of X-rays. Six brief requirements are listed for X-ray diffraction equipment, but they are general in nature and would be difficult to enforce as regulation

REFERENCE Q

Applies To: Analytical X-ray Equipment

Title: Safety Considerations in the Design of X-ray Tube and Collimator Couplings on X-ray Diffraction Equipment,
Apparatus and Standards Committee,
American Crystallographic Association (ACA)

Type: Class B - Committee report

Intended For: Users and designers of X-ray diffraction equipment

Contents: This report deals with the problem of radiation hazards associated with the X-ray tube and collimator coupling on X-ray diffraction equipment and offers recommendations and design criteria for minimizing these hazards. Schematic drawings and photographs of couplings and shutters are included. The report is partly based on discussion at the 1960 meeting of the ACA.

REFERENCE R

Applies To: Analytical X-ray Equipment

Title: Radiological Protection in the Use of X-ray Crystallographic and Spectrometric Equipment
Department of Employment and Productivity, London

Type: Class B - Advisory pamphlet published by the British Government.

Intended For: Users of X-ray crystallographic and spectrometric equipment in the research and teaching fields.

Contents: This 11 page document first explains the hazards associated with X-ray crystallographic and spectrometric equipment. After discussing the basic protection policy, the details of equipment design and modification (for safety reasons) is discussed. Maintenance, operating procedures, and radiation monitoring are also covered. While not written to be used as a legal standard, it could be used as the basis for one.

REFERENCE S

Applies To: Analytical X-ray Equipment

Title: Radiation Hazards Associated With X-ray Diffraction Techniques,
Commission on Crystallographic Apparatus,
International Union of Crystallography.
Published in Acta Crystallographica (1963) 16, 324

Type: Class C - Unauthored guidance

Intended For: Users of X-ray diffraction equipment (Specifically not for X-ray fluorescence spectrography)

Contents: Describes hazards associated with X-ray diffraction equipment including a detailed discussion of the various sources of unwanted radiation. Guidance in the use and in consideration of design details is given. Topics covered in this three page article are:

Sources of Unwanted Radiation
Detection of Stray Radiation: Personnel Monitoring
Factors Responsible for the Hazards
Comments Concerning the Hazards
General Recommendations

APPENDIX B

REPLIES FROM MANUFACTURERS

Appendix B

REPLIES FROM MANUFACTURERS

Part A - PARTICLE ACCELERATORS

The specific questions that were presented to the accelerator manufacturers and their replies (which have been extracted and paraphrased as necessary to reduce the volume of data that could be presented in this study) are as follows:

Question 1: What printed materials are provided by you with respect to radiation hazards, safety instructions, and the operation of all accelerator equipment sold by your company?

Reply A: An operating manual that defines start-up, trouble shooting, and maintenance is provided to the purchaser. When a procedure is described which can lead to production of radiation, it is clearly noted. A health physics procedures manual is also provided at the customer's request. The manual was approved by the State of California for operating accelerators in the company's facilities.

Reply B: The following printed materials are provided the purchaser:

Operating and maintenance manuals cite warnings regarding hazards and safety precautions.

Equipment specifications cite certain radiation hazards. One paragraph refers to acceptance tests at the purchaser's site; it states that no test runs will be undertaken when conditions of radiation exposure exceed accepted tolerance levels for personnel (NBS, AEC, or State regulations). Another section also discusses radiation protection, in that the company assumes no liability whatsoever for damages due to radiation. The company advises that the purchaser set up his own safety program using appropriate AEC and NBS regulations.

Standard Conditions of Sale state that the manufacturer assumes no responsibility for damage caused by radiation produced by equipment, and cautions the purchaser to make sure that equipment is operated by experienced and authorized personnel only.

Instruction sheet entitled "Radiation Warnings and Recommendations," warns personnel that particle accelerators are capable of producing radiation which might cause serious and possibly fatal injury. This information appears to be the most specific and comprehensive set of instructions that is made available to the purchaser by this company. Information sheets on representative radiation levels around the accelerator under various conditions are provided to assist the customer in planning radiation shielding.

Suggested accelerator layout notes door safety interlocks and indicates in "notes" that the purchaser is responsible for providing adequate radiation protection and must conform to any Federal, State, or local regulations. Suggested installation layout notes safety interlocks for doors leading into target and accelerator rooms, and mentions again the purchaser's responsibility to provide adequate radiaton protection and to conform to Federal, State, or local regulations.

Reply C: Neutron Generator Instruction Manual's introduction discusses the purchaser's responsibility to provide adequate shielding for operating personnel. Suggested safety precautions are given to prevent accidental exposure during installation and maintenance.

The manual discusses responsibility of workers inside the neutron shield to take suitable precautions to control their exposure time and to provide X-ray, neutron, and gamma radiation shielding.

It also discusses the need for a radioactive by-product license for the titanium tritide target, neutron flux monitors, and other radiation monitors--pocket dosimeters, film badges, and proportional counters are also discussed.

The manual discusses safety considerations concerning removal of the ion pump elements (wearing of plastic disposable gloves).

One section discusses certain checks that should be made before attempting to run up the accelerator, such as clearance of all personnel from the accelerator area, testing of health monitoring equipment for proper operation, and verification of neutron monitoring equipment for proper operation. Another section discusses shielding requirements in detail. Two shielding designs are noted, an open geometry arrangement, and a closed geometry arrangement to reduce neutron flux, and the need for additional X-ray shielding is mentioned.

A service memo discusses certain precautions which are recommended to the company servicemen who are involved in maintenance of accelerators.

Reply D: Operation and maintenance manuals are supplied for each accelerator sold. Included in each manual are safety instructions for the particular model accelerator. The safety instructions describe all known personnel and equipment hazards--radiation, electrical, and miscellaneous.

The company provides on-the-job instruction to customer personnel during assembly and testing. Factory training course on maintenance and operation of the accelerators (which includes safety information) is available to each customer upon request.

The general operating and safety procedure manual for company personnel is a 13 page booklet which discusses in detail radiation safety practices and procedures. The reply from the company did not mention if this booklet was available to their customers.

Reply E: National Bureau of Standards Handbooks 76 or 93, as appropriate, are provided with the apparatus at installation.

An X-ray form is inserted into the apparatus' instruction manual. The circular discusses the possible hazards, and refers the purchaser to the NCRP and ICRP recommendations regarding X-ray protection. Also the company states that it has no responsibility for injury or damage which may result from exposure to X-radiation.

A safety precautions insert is provided by the company in their individual instruction manuals. The statements deals with specific safety precautions which are recommended by the company in the use of electron beam units. It discusses such topics as ozone generation, ventilation, secondary radiation production, circuit interlocks, a radiation survey by radiation physicist, radiation monitoring service, etc.

Installation recommendations discusses probable shielding requirements, access, interlocking and other safety precautions.

Reply F: Technical bulletins introduce the user to the subject of tritium hazards and shielding for neutron protection.

Operations manuals for accelerators include sections on recommended procedures pertaining to safety. The manuals discuss such topics as operational and shutdown radiation hazards, tritium target hazards, radioactive materials storage and waste disposal, and facility shielding.

The company recommends that users secure copies of AFRRI-TN 66-5 which describes target changing procedures. They also recommend NBS Handbook 63 which describes shielding against neutrons up to 30 MeV.

Reply G: A chapter in the operational manual is devoted to safety. The topics covered in this chapter include radiation hazards, noxious gases, high voltage dangers, recommended safety devices and recommended operational procedures.

Reply H: Instruction manuals and other material covering operation, maintenance and safety precautions are supplied with all accelerators. An accelerator shielding guide and typical shielding configurations are provided.

Reply I: An instruction manual is supplied to all customers. Specific technical descriptions regarding potential health hazards associated with the accelerators are contained in an appendix and another appendix defines the terms used in describing biological dose. A chapter is devoted to specific information regarding facility shielding requirements and typical installations.

Question 2: What steps are taken to instruct persons in the safe operation of accelerators, such as courses, printed instructions or materials, or other devices or procedures?

Reply A: An instruction manual includes topics on equipment description, theory of operation, safety precautions, operating procedures to prevent accidental exposure, equipment damage, and maintenance procedures to prevent accidental exposure.

Training for customer personnel occurs at the customer's site while reassembling and testing the unit, and at the manufacturer's plant while assembling and testing.

Optional formal classes conducted at the customer's site are also provided.

Reply B: Instruction manuals are provided with each apparatus with references made to related safety practices. Bureau of Standards handbooks are also supplied.

Informal classes are offered at the factory or customer's site regarding operation and maintenance and related safety practices.

Reply C: The written instruction manual on the operation of the accelerator discusses the type of radiation the machine can produce.

An in-plant course and a course at the customer's facility stress the various radiological hazards produced by the accelerator.

Reply D: During the installation period of the customer's machine, the company engineer supervises the assembly. The field engineer explains and demonstrates the purpose and performance of all of the various components and systems.

An instruction manual (operating and maintenance instructions) includes warnings to radiation hazards.

Reply E: An instruction manual with each unit discusses radiological hazards.

Factory training is provided to the customer on the safe use of accelerators.

Pre-installation planning is offered during which the needs for personnel safety, interlocking, and monitoring are discussed.

Reply F: In addition to the printed instructions discussed in questions 1, installation and service personnel review the safety procedures with the user at the time the machine is installed.

Reply G: After the installation has been completed, the engineer remains on site for at least one additional day, instructing the customer in the proper operation and use of the equipment. During this period, the engineer specifically emphasizes safe operation of the equipment. In addition, one of the accelerator manuals which are supplied with the equipment gives detailed information on acceptable radiation tolerance levels, references to AEC regulations and more extensive literature concerning radiation protection.

Reply H: Customer personnel are given operation, maintenance, and safety instructions by manufacturer's installation engineers and technicians. The manufacturer also conducts courses for customer personnel and safety considerations are a part of the material covered.

Reply I: The installation engineer trains the customer's personnel in operation and maintenance of the accelerator during installations and acceptance testing. A preinstallation manual is provided to the customers which deals with radiation protection also.

Question 3: Do you offer to design, build, and/or install safety interlock systems for particle accelerators you sell? Do customers use the safety system designed, built, and installed by you, or do customers use other designs? Do you evaluate the safety effectiveness of interlock systems designed and installed by other companies on accelerators you sell?

Reply A: The company does not offer to design, build, and/or install safety interlock systems for accelerators it sells.

It is not company policy to evaluate the safety effectiveness of interlock systems designed and installed by other companies.

The customer is advised and expected to devise, provide and install his own systems.

Available information on the subject is provided to the customer along with accelerator devices necessary to connect with the customer's safety system.

Reply B: Protection devices such as automatic HV shorting mechanism, personnel gate interlock, cooling water flow interlock, HV zero start interlock, HV overload relay, HV over-voltage relay, HV spark gaps, HV surge resistor, and removable master key on control panel are provided and installed by manufacturer personnel. The customer must use the protective devices available, otherwise the unit will not function. (Note, however, that only the gate interlock and removable master key can really be considered personnel safety devices). As an accomodation, company personnel will install other protective devices the customer may have available.

The manufacturer is not aware of interlock systems installed by other companies on their accelerators and the manufacturer advises its customers that equipment warranties are voided if the equipment is modified by other than manufacturer personnel.

Reply C: Wherever there is a possibility of energizing a control which can produce a dangerous situation such as radiation or high voltage, suitable interlocks or provisions for including relays are furnished so that these controls cannot be energized until suitable safety precautions are taken.

Design of an interlock system or instructions to enable the customer to connect into the existing interlock system in the accelerator are provided.

Reply D: Each accelerator is equipped with a protective interlock system. Equipment protection circuitry includes a variety of switch devices designed to prevent overtravel or overrunning. Covers and doors which protect personnel from thermal, electrical, and other hazards are interlocked.

Provisions are made to wire any customer's safety interlocks into the system. The complete system is tested by the manufacturer and the customer before the accelerator is used.

Before making interlock modifications the customer usually consults the manufacturer. The manufacturer does not make a formal evaluation of the customers interlock system design or proposed changes, and does not approve or sanction such changes.

The manufacturer would have to receive a separate safety study contract to formally evaluate the customer's safety effectiveness of his facilities.

Reply E: The manufacturer does not offer to design and build or install safety interlock systems (or warning light and sounder systems). A suggested system schematic and parts list regarding this is available upon request by the customer.

Review of customer's plans for electrical and mechanical compatability with the manufacturer's apparatus is offered at which time the manufacturer, when requested, will make suggestions to assure the greatest safety without specifying in detail the necessary components.

Reply F: Provisions for installation of safety interlock systems are made and the manufacturer recommends such installation.

Consultation with the use and estimates of the effectiveness of his shielding are provided.

A red light and an emergency shutdown button are provided so that the unit can be turned off if a person should be in the accelerator room and all interlocks and other safety provisions fail.

Reply G: We do offer our services to advise or design safety interlocks systems provided bidders ask for such help. However, we do not build special interlocks other than a high voltage lockout and a safety interlock string for the customer's vault door and/or other safety interlocks.

Customers normally use safety systems incorporated in our accelerators and some add additional interlocks depending on the installation.

We do not evaluate, in general, effectiveness of interlock systems designed and installed by other companies. However, we do offer advice upon request by customers, without legal involvement for same.

Reply H: The manufacturer will supply design assistance regarding interlock and alarm circuits at the request of the customer. When the customers use safety systems designed by the manufacturer, the manufacturer supplies installation supervision and assistance. Installation is normally done by local contractors to conform with union requirements and to avoid conflict with local laws and ordinances. Customers are advised that regardless of whether the manufacturer's assistance is utilized, shielding and safety devices must be approved by experts in the radiation field. Where customers employ independent experts, the manufacturer will provide design and shielding data to assist them in the design of a suitable and safe installation.

Reply I: We do not specifically offer to design and build safety interlock systems for our customers. However, we have in the past installed such systems in our customers' facilities. We advise our customer, before the fact, regarding radiation shielding requirements. We evaluate the installation after it is completed and advise our customers of any changes we feel are desirable for safer operation of the equipment.

Question 4: What statements do you provide the buyers which indicate your responsibility in connection with any accidents or continuing radiation exposures generated by the equipment you sell?

Reply A: A statement is included in the equipment specification that the company assumes no liability whatsoever for damages due to radiation, and the customer must set up his own radiation protection program using recommendations such as those set forth by the AEC and NBS.

Reply B: We provide no special statement to our customers indicating responsibility for radiation exposure generated by the equipment we manufacture and sell.

Reply C: In the Standard Conditions of Sale is a statement which describes the company's liability to radiation produced by the accelerator after it is installed. The company feels that it is the customer's responsibility for radiological health safeguards, and it assumes no liability for damage to the customer's personnel or other property.

Reply D: Printed material provided by the company states that: "It is assumed that all persons authorized to use the equipment are cognizant of the danger of excessive exposure to X-radiation and the equipment is sold with the understanding that the company, its agents and representatives, have no responsibility for injury or damage which may result from exposure to X-radiation. Various protective materials and devices are available. It is urged that such materials or devices be used."

Printed material provided by the company also makes no expressed or implied warranty or representation that the plans and specifications are sufficient to protect persons or property from damage. It also recommends that a qualified expert be consulted for the design and construction of the installation so that it might adequately meet local and national radiation protection standards.

Reply E: No statements.

Reply F: The company believes that its responsibility extends to the point of warning each customer that radiation safety is a matter of controlling the operational routine and that radiation safety be a primary concern of the customer.

Any safety device can be intentionally bypassed, and hence, the emphasis must be on the routine of operation. Essentially only a means for turning the radiation off at will is provided.

Reply G: The company in its bulletins, manuals, and related brochures defines the hazards that exist, proposes a solution, and recommends that the customer maintain the instrumentation necessary to be sure that the solution is adequate.

Reply H: Operational responsibility, of course, rests in the customer since he is the only party in a position to assure safe practices.

Reply I: The standard conditions of sales and warranty includes a statement that the seller assumes no liability for damages occurring to personnel or property due to radiations produced by the apparatus after it is installed in the buyer's facility.

Part B - EXAMPLE OF LETTER SENT TO MANUFACTURERS

Dear Sir:

Under the recently enacted Public Law 90-602 (copy attached) the Secretary of DHEW has been assigned responsibility to conduct certain studies as specified in section 357 of the bill. Specifically, section 357 (a) (2) requires "a study to determine the necessity for the development of standards for the use of nonmedical electronic products for commercial and industrial purposes."

In order to successfully carry out this study, it will be necessary to determine 1) the magnitude and extent of use of radiation-producing equipment used for nonmedical applications, and 2) the existing radiation safety usage guidelines and recommendations, provided by your company through the sale or service of its equipment. We are therefore requesting your cooperation in assisting us to obtain such information. Since the results of the study are to be presented to Congress on or before Jan. 1, 1970, we would appreciate receiving your reply by May 16, 1969 in order to allow us sufficient time to collate and assimilate the information, and to prepare the final report.

Our records indicate that (name of company) manufactures (name of product). We would like you to provide us with: 1) an estimated number of (name of product) sold by your firm over the past 5 years, 2) brief summaries or copies of any radiation safety guidelines or procedures provided by your company to the buyer which relate only to the use of the particular device (please omit specifications), and 3) a projected estimate of the total number of (name of products) that your company expects to market through 1972.

Confidential information provided will be handled in accordance with Title 18, section 1905 of the U.S. Code.

Your cooperation would be quite helpful and sincerely appreciated. Should you have any questions please do not hesitate to contact me.

Sincerely yours,

John C. Villforth, Chief
Division of Medical Radiation Exposure

Part C: INDUSTRIAL RADIOGRAPHIC AND FLUOROSCOPIC EQUIPMENT MANUFACTURERS

Reply J: In their operating manuals they include a warning statement which indicates that proper operation of the equipment is mandatory to protect individuals, that no untrained person should be permitted to operate the equipment. They recommend that further study of radiation protection information from U.S. Department of Commerce, National Bureau of Standards is important.

They also include in their list of precautions, which mainly apply to the equipment safety, at the top of the list a health safety recommendation about standing in the vicinity of the tube head and primary X-ray beam.

In the installation instructions they recommend the blocking of the X-ray beam with a lead cover. Also, that the unit should not be operated unattended.

Reply K: "We have no written radiation safety guidelines. Our philosophy is as follows: If the equipment is to be used in a shielded room or a shielded cabinet, we strongly recommend to our customer that the room or cabinet be designed as an 'exempt' installation as defined in Handbook #93 published by the Department of Commerce, National Bureau of Standards.

"If the equipment is to be used in the field, we recommend to the customer that he purchase radiation safety instruments in order to monitor the radiation area which should then be roped off. We further recommend that personnel in the area wear radiation badges."

Reply L: "Customers are told to notify State or city industrial hygiene departments responsible in their locality."

Reply M: We send a copy of National Bureau Standards Handbook 93 with each machine that produces radiation. "Specific procedures and instructions are included with each apparatus outlining the proper steps for energizing the unit. Each instruction manual incorporates an initial paragraph relating to X-ray protection,..."

Quote from paragraph Exhibit A, "It is assumed that all persons authorized to use the equipment are cognizant of the danger of excessive exposure to X-radiation and the equipment is sold with the understanding that....have no responsibility for injury...."

Reply O: Send a letter upon receipt of a purchase order which indicates production of X-rays dangerous to personnel and enclose a copy of NBS Handbook 93.

Before delivery of the equipment can be made they require that a signed statement from the customer be received. It states that the warning notice has been read and that the equipment will be installed in accordance with the company's instructions. Within the instruction manual are warnings pertaining to radiation protection.

Part D. ANALYTICAL X-RAY EQUIPMENT MANUFACTURERS

Reply P: This company supplies the buyer with an instruction manual which makes reference to radiation protection. Specific guidance in this manual includes:

a) a caution to block the primary beam with lead should it be necessary to service the machine while in operation and with the sheet metal cover removed.

b) mention that the x-ray shutter must be closed when the sample cup is removed and that the X-ray power is automatically shut off if this procedure is not followed.

c) X-ray tube shielding check.

d) notification of need to follow general radiation safety recommendations and, where appropriate, requirements of the State of California. Also, recommends radiation hazard surveys by a competent consultant.

e) recommendation for formal safety administration; specifically, the posting of names of employees permitted access to radiation areas; appointment of a person to be responsible for radiation monitoring of personnel; posting and control of radiation hazards; and employee safety instruction.

f) other administrative practices.

Reply Q: The company supplies the customer with a copy of Handbook 93, "Safety Standard for Non-medical X-ray and Sealed Gamma Ray Sources, Part I-General." Service engineers are provided with survey meters for use during servicing of equipment and the company recommends that customers purchase a survey meter. Caution labels are provided for placement on the machine panel, shutter, and sample cap.

In addition, a written set of safety rules are reviewed with the user, and the service engineer recommends their posting.

Reply R: This British company apparently does not market radiation producing equipment within the United States. A X-radiation warning notice is given to purchasers of machines which may produce radiation.

Reply S: An inconspicuous three sentence paragraph in the operation and maintenance manual states that the user should:

a) avoid the X-ray path

b) mask the window when adjusting the spectrometer

c) cut off electron beam or block X-rays before making readjustments.

Reply T: This company manufacturers X-ray tubes for analytical X-ray equipment and is part of another company which was also included in this survey. The reply originated at teh parent company and no specific information was provided regarding the safety policy of the company in question.

Reply U: This British company manufacturers X-ray diffraction equipment and tubes. They do not normally issue printed radiation safety guidelines to their customers, but usually incorporate a statement in the service manual to the effect that customers should be familiar with existing radiation safety regulations.

Reply V: A two page "Warning Notice" has been prepared by the company radiation officer and presumably is given to all customers. This notice makes general radiation safety recommendations as well as several which pertain specifically to analytical X-ray equipment. The notice also recommends that the user be familiar with "National Bureau of Standards Handbook 'X-ray Protection' HB 76" and "The Recommendations of the International Roentgen Ray Committee on X-ray Protection."

Reply W: The operating instructions for this company's "small camera generator" include a four-page safety precaution. It is unknown what information is given to purchasers of other analytical X-ray equipment produced by this company. The safety precaution consists of a reprint of a portion of an article by R. Rudman which appeared in the January-June 1967 Journal of Chemical Education. This precaution discusses the hazards associated with analytical X-ray equipment and lists other reference materials. Recommended administrative procedures are also given.

The company's advertising brochure emphasizes safety features which are incorporated in the equipment design.

Reply X: The reply from this company states: "We have no summaries or copies of radiation safety guidelines to furnish you as we are only the manufacturer of the glass envelope which fits into the equipment. Our X-ray glass inserts are furnished for either self-contained mobile units, or large stationary inspection units, and all radiation protection is included with this equipment. Therefore, we have no information to offer you along these lines.

Reply Y: A copy of National Bureau of STandards Handbook 93 "Safety Standard for Non-Medical X-ray and Sealed Gamma-Ray Sources" is given to each user. Also, specific operating procedures and in instructions are included in a manual. Each of these instruction manuals incorporate an initial paragraph which warns the user to take caution in the use and maintenance of the equipment. Recommended safety reference materials are listed. Also, the company offers to "assist and cooperate in placing this equipment in use."

Reply Z: This company, which manufactures X-ray tubes, made the following statement: "Inasmuch as we manufacture and sell X-ray tubes only for incorporation in X-ray equipment units manufactured and/or sold by others, we have not undertaken to give complete radiation safety instructions for the use of tubes sold by us, which can be given meaningfully only in connection with the total apparatus package."

Reply AA: This company produces electron microprobe analyzers and states: "At present we do not supply radiation safety guidelines in written form to our customers."

Reply BB: It is the policy of this company, upon the receipt of a purchase order for equipment, to send the customer a letter, two copies of a Warning Notice, and a booklet entitled "Safety Standard for Non-Medical X-ray and Sealed Gamma-Ray Sources, Part 1, General." This letter states that X-rays can be dangerous and asks that an acknowledgment (at bottom of Warning Notice) be signed and returned to the company. This acknowledgment states that the customer has read the Warning Notice and will install equipment according to instructions provided in this notice. The signed acknowledgment must be received before the equipment is delivered.

It is also asked that if the apparatus is resold, a similar warning notice be given to the purchaser.

The Warning Notice lists safe precautions for use and operation of X-ray producing equipment. These include administrative procedures as well as briefly mentioning such topics as shutters, interlocks, maintenance, and servicing.

All instruction manuals contain a condition of guarantee in which it is stated that the guarantee "does not cover damage resulting from carelessness or failure to follow operating instructions." The aforementioned Warning Notice is also cited as a condition of guarantee.

The instruction manuals also specify safety precautions in those sections where alignment, cleaning, and maintenance procedures are described.

Reply CC: The first page of the instruction manual for equipment in which X-ray tubes are used contains a radiation warning statement and refers the user to NCRP reports No. 33 and 34. Also, the customer is given a copy of NCRP Report No. 33 and National Bureau of Standards Handbook 76. When it is available, NCRP Report No. 34 will be given in lieu of Handbook 76.

Equipment in which X-ray tubes are used is designed and manufactured to comply with the guidelines established in NCRP No. 33.

An "Owner Safety Manual" is included with each major piece of equipment. This manual recommends that a radiation survey be made of all new installations. It also points out that while company employees make some radiation measurements, these men are not qualified experts as defined in NCRP No. 33, and these measurements do not substitute for a complete radiation protection survey.

Reply DD: The reply from this Japanese company follows: "All the X-ray equipment destined for the domestic market is designed in conformity with the Japanese Radiation Safety Regulations. In addition to this standard, the X-ray equipment to be sold in the U.S.A. is designed to conform with the safety standard specified by our U.S. distributor." "This (distributor's name) specification applies to all of our X-ray equipment supplied to them since early this year. We trust you are already informed by them of their standard for radiation protection."

Reply EE: Machines sold by this company are manufactured in Germany. The machines are checked for radiation safety at the factory in accordance with the regulations of the "Physikalish-Technische Bundesanstalt, Braunschweig."

All X-ray customers are supplied with a "Caution Radiation Area" sign.

Reply FF: Customers are given a copy of the Health, Education, and Welfare pamphlet "Radiation Safety Recommendations for X-ray Diffraction and Spectrographic Equipment."

In addition, the first three pages of the instruction manual for a diffractometer briefly discuss radiation protection and warn of the potential hazards. The user is advised to be familiar with the recommendations of the NCRP, the International Commission on Radiation Protection, and the rules and regulations of certain State health offices.

It is further stated in this manual that the "equipment has been designed to incorporate all practical protection against all generated X-radiation other than the useful beam and against high voltage parts."

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APPENDIX C

ACCIDENTS INVOLVING NONMEDICAL IONIZING RADIATION PRODUCING EQUIPMENT

Appendix C

ACCIDENTS INVOLVING NONMEDICAL IONIZING RADIATION PRODUCING EQUIPMENT

Part A - PARTICLE ACCELERATOR INCIDENTS

Incident 1

Equipment Involved: Linear Accelerator
Date & place of Incident: 1967, California
Exposure to the Victims: Six graduate students at a University were exposed to X-radiation from a linear accelerator, ranging from 920 to 2690 mrem.
Injury to Victims: No clinically manifested radiation injury was reported.
Circumstances: Six graduate students, who were involved in the initial tune-up of the linear accelerator, entered a high radiation area by overriding the interlocks on the doors which prevented access to this area. During the tune-up of the RF phase of the linac operation, the students were exposed to X-radiation.

Incident 2

Equipment Involved: Linear Accelerator
Date & place of Incident: 1967, California
Exposure to the Victim: Employee received an occupational exposure of 2100 mrem in the second month of a quarter and a subsequent exposure of 900 mrem in the final month of the quarter, thereby exceeding permissible quarterly exposures.
Injury to the Victim: No injury was specified
Circumstances: An investigation indicated that the overexposure was received while tuning a klystron amplifier without adequately estimating and controlling anticipated exposures.

Incident 3

Equipment Involved: 1200 kV electrostatic generator
Date & Location of Incident: 1944, Massachusetts
Exposure to the Victims: Approximately 1000-2000 "tissue rem."
Injury to Victims: Severe radiodermititus developed over much of the body areas of the exposed individuals.
Circumstances: The target of an electrostatic generator, used for medical purposes in a large hospital, was removed in order to determine the size and location of a focal spot using a piece of film. It was known that there was a definite danger in exposure to the direct beam, but it was thought that it would be safe to stand at a distance of several feet. Consequently, six staff members entered the room while the machine was in operation to observe the fluorescence due to the electron beam, thus resulting in their exposure.

Incident 4

Equipment Involved: Linear Accelerator

Date & place of Incident: Date not specified, Unknown University

Exposure to Victims: Not stated

Injury to the Victims: No clinical manifestation of injury was found

Circumstances: Two research assistants entered a target area of a linear accelerator without notifying the operator. They failed to remove an interlock key and ignored warning lights, signs, and the sound of accelerator klystron pulsers. One worker adjusted the target by hand and made a visual alignment. He realized that a blueish irridescence occurred in his eyeglasses and left the target area immediately.

Incident 5

Equipment Involved: Linear Accelerator

Date & place of Incident: Date not specified, Unknown University

Exposure to Victim: Not stated.

Injury to Victim: No signs of biological damage was found

Circumstances: A part time worker, whose job it was to fill vacuum pump traps, ignored warning devices and signs, climbed across the top of the accelerator shielding into an exposure area. He thus avoided the interlocked gates. The operator, assuming the worker was through with his work, proceeded to warm up the machine and operate it. The worker was not exposed to the primary beam, however.

Incident 6

Equipment Involved: Electron Linear Accelerator

Date & place of Incident: 1959, California

Exposure to Victims: Seven individuals were exposed. It was determined that film badges had been exposed to 200 keV gamma radiation An exposure dose of 41 r was assigned to one physicist. This dose was received in a period of about one minute, which was the established time that the physicist worked alone on certain places in the cell. The next highest reading of 400 mR was received by another physicist. All other individuals received less than 50 mR.

Injury to Victims: No clinical manifestation of radiation injury was reported.

Circumstances: A new electron linear accelerator was being operated to accumulate data to enable the engineering section to design a permanent piece of equipment for this machine. A number of remote operating circuits were not in operation. The barrier was temporarily replaced by a 4'X4' piece of plywood and a warning sign. A series of adjustments were being made on beam defining plates. Radiation surveys were made with negative results when personnel entered the cell after the first three adjustment runs. No survey was made after the fourth and fifth runs. A survey was made after the sixth run and showed an approximate radiation level of 1000 r per hour. During all entries to the cell, the key which was designed to lock all controls in the "off" position was removed from the control panel. Reliance was placed for safe operation on an incomplete safety interlock circuit.

Incident 7

Equipment Involved: Van de Graaff Accelerator

Date & place of Incident: 1960, New Mexico

Exposure to the Victims: By indirect measurements using film badges, a dose of approximately 760 rads to the face of one employee was estimated and approximately 53 rads total body dose to another employee was estimated.

Injury to the Victims: The individual receiving the larger dose showed multiple radiation burns in the middle section of the face, abdomen, and both hands. No report of clinically manifested radiation injury were shown for the other individual.

Circumstances: While setting up an experiment in front of the beam tube, an employee was accidentally exposed to the electron beam eminating from the Van de Graaff accelerator. The machine operator put the machine on self charge, with the employee's consent and knowledge. The employee entered the beam room. This was done to check the self charge rate and limit of the machine. The beam current and belt charge were not turned on, these being the normal source of electrons. The employee proceeded to the end of the beam tube and began setting up his experiment. After approximately two minutes, he came out of the beam room, since his face felt warm. He then went to the washroom and washed his face. The employee asked the operator if there was any residual beam current. The operator stated that the beam current was not on but that he would check. The operator then entered the beam room with a low range survey meter and made a measurement in front of the beam tube. The meter pegged at 20 mrems.

Incident 8

Equipment Involved: Gradient Synchrotron

Date & place of Incident: 1963, Illinois

Exposure to Victims: Two individuals received whole body exposures of 3.8 rem and 2.8 rem respectively.

Injury to the Victims: No injury specified

Circumstances: Employees were exposed while making adjustments on a gradient synchrotron. Before the work of adjusting the synchrotron began, the beam stopper was inserted into the synchrotron to prevent exposure to the employees. However, the correct beam stopper was not inserted and the employees carried on their assignment unaware of this.

Incident 9

Equipment Involved: Cyclotron

Date & place of Incident: 1964, California

Exposure to the Victims: One individual received the whole body dose of approximately 3.4 rem.

Injury to the Victim: Not specified

Circumstances: An employee was exposed to radiation while removing targets, which were bombarded by the cyclotron. These targets were removed from a vacuum chamber in a high level cave.

Incident 10

Equipment Involved: Linear Accelerator

Date & place of Incident: 1965, Illinois

Exposure to Victim: One individual received the following doses: to the interior of the body, 0.2 to 5 rads; to the right hand, 42,000 to 240,000 rads; to the right foot, 200 to 29,000 rads.

Injury to the Victim: Double amputation, right hand and right foot.

Circumstances: An industrial worker was accidentally exposed to an electron beam when he walked into a room to place an octagonal mold on a conveyor belt near the output port of an operational accelerator. The accelerator was mounted so that 10.8 MeV electrons were directed downward after emerging into the air from a vacuum chamber at a height of 75 cm from the floor. The electron beam spread rapidly in its downward course due to its intrinsic angular distribution coupled with multiple scattering in the window and air. At 46 cm above the floor, it struck a conveyor belt, whose function it was to carry industrial products to the beam. The conveyor system occupied part of the entryway to the accelerator room. In order to accommodate this conveyor system, the bottom of the door guarding the entryway had been sawed off. The worker gained entrance to the accelerator room through the resulting gap without tripping the electrical interlocks.

Incident 11

Equipment Involved: Accelerator - type not specified

Date & place of Incident: 1966, location not specified

Exposure to the Victim: One individual was exposed to a dose of approximately 300 rem to one foot.

Injury to Victim: Not specified

Circumstances: A technician was exposed to an estimated 300 rem of X-ray to one foot in an accelerator incident. This is the only information available.

Incident 12

Equipment Involved: 3 MeV Van de Graaff Accelerator

Date & place of Incident: 1967, Pennsylvania

Exposure to the Victims: Three individuals were involved in the exposure. Two men received approximately 500 to 600 rem whole body dose. The third individual received approximately 100 to 200 rem whole body dose. Exposure to the extremities may have been higher.

Injury to the Victims: One technician had both hands amputated and a spot of tissue deterioration recently appeared on the foot of this individual. Further information regarding injury to the technician and the two other research chemists have not been reported, however, such information will undoubtedly be published in the near future.

Circumstances: A Van de Graaff accelerator was being used for activation analysis. The exposure took place apparently as a result of the accelerator not shutting off after the irradiation of a sample of oil. The three men entered the target room, removed the sample, and then attempted to locate the source of trouble with the target cooling system. Possible explanations for the exposure appeared to suggest the failure of the safety interlock system to shut off the accelerator and the lack of, or failure to adhere to, proper operating and radiation safety procedures.

Incident 13

Equipment Involved: Cyclotron

Date & Place of Incident: 1965, California

Exposure to the Victim: One individual was estimated to have received an external whole body radiation exposure of approximately 3 1/2 rem. This was concluded from a film badge reading.

Injury to the Victim: No clinical manifestation of radiation injury was specified.

Circumstances: An employee was preparing for an experiment in a cave area. The radiation exposure was presumed to have occurred during a beam tuning period, while the employee was working in a cave adjacent to a cyclotron vault. The exposure was assumed to have occurred because of a narrow crack in the shielding wall between the cave and the vault. Although there was reasonable doubt that the film badge reading was sustained as a whole body exposure, nevertheless, it was charged to the employee's record.

Incident 14

Equipment Involved: Van de Graaff Accelerator

Date & place of Incident: 1965, Tennessee

Exposure to the Victim: One individual received an exposure of approximately 51 rem to the left forefinger.

Injury to the Victim: Not specified

Circumstances: An experiment was being conducted by a physicist involving the use of the Van de Graaff machine. While he was in the target room, the beam shutter failed permitting the proton beam to impinge on a tritium gas target in the shielded target room. This resulted in a yield of about a 6×10^9 neutrons per second. He worked in the vicinity of the neutron source for approximately 15 minutes and held his finger adjacent to the tritium target for approximately 10 seconds.

Incident 15

Equipment Involved: Ion linear Accelerator

Date & place of Incident: 1965, California

Exposure to the Victim: One individual received approximate whole body quarterly exposure of 3 rem.

Injury to the Victim: No clinical manifestation of radiation injury was specified.

Circumstances: Modification of the water cooling system for the post stripper tank, and adjustments of focusing magnets in an ion linear accelerator in preparation for startup were being performed. Although the employee was forewarned that his exposure was approaching the quarterly limit, he continued start up preparations knowing that he might exceed the quarterly limit.

Incident 16

Equipment Involved: Linear Accelerator

Date & place of Incident: 1967, Utah

Exposure to the Victim: One individual was exposed to approximately 1 rem.

Injury to the Victim: Not specified.

Circumstances: A radiographic technician turned off a 24 MeV linear accelerator and proceeded through two interlocked doors to the accelerator room. He noted an unusual humming sound coming from the accelerator and upon returning to the control console noted the machine indicated X-radiation without the "exposure on" button being pushed. Subsequent investigation revealed carbonized material had formed on a relay in the safety interlock system. An independently operated lead shutter in front of the X-ray port operated normally and saved the technician from a higher radiation exposure.

Part B - INDUSTRIAL RADIOGRAPHIC AND FLUOROSCOPIC X-RAY EQUIPMENT

Incident 1

Equipment Involved: Radiographic X-ray Machine

Date & place of Incident: 1968, State of Washington

Exposure to Victim: Maximum exposure was estimated to be approximately 276 R to the dermal layer of skin of the head.

Injury to Victim: No clinical manifestation of radiation injury was reported.

Circumstances: A graduate student, engaged in radiography, was exposed to soft radiation when the X-ray control circuit of the radiography unit permitted the tube to remain energized after the X-ray timer had turned off. The unit was operating at approximately 49 Kvp and 10 mA and utilized a beryllium window with no additional filtration. It is believed that the victim was exposed for a period ranging from 4 to 8 minutes while his hands and head were directly under the tube in the primary beam.

Incident 2

Equipment Involved: Radiographic X-ray Machine

Date & place of Incident: 1953, Kansas

Exposure to Victim: Dose to the victim has been approximated at ranging from 900 rem per minute on the palm surface of the hand to as high as 44,000 rem per minute on the back of the hand. Duration of the exposure has been estimated between 3 and 5 minutes.

Injury to Victim: Extremely severe burns to the right hand, which resulted in eventual amputation. A typical sequence of clinical manifestations of the injury occurred beginning with swelling of the hand and fingers, severe edema, and eventual debridement and bleeding. This subsequently resulted in extensive necrosis which required amputation of the hand.

Circumstances: Injury occurred to an untrained industrial worker while he carried out unnecessary and unauthorized experimentation. The X-ray tube operated at 50 mA and 60 KV.

Incident 3

Equipment Involved: Radiographic X-ray machine

Date & place of Incident: 1968, Tennessee

Exposure to the Victim: Unable to determine true exposure, however, an approximation resulting from a duplication of the parameters involved, revealed that the dose could have been anywhere between 100 and 500 rem to any part of either the index finger or thumb of the right hand.

Injury to the Victim: No clinically manifested injury was cited, however, the victim did complain of a numbness in the region of the ventral surfact of the second finger and thumb of the right hand.

Circumstances: An employee was performing an experiment on a radiographic X-ray unit and for personal reasons had apparently short circuited the door interlock on the machine so that he could be in the room while the machine was energized. The machine was operating at approximately 60 Kvp for a period of 1 to 3 seconds. It is believed that the right hand was in the primary beam during this time.

Incident 4

Equipment Involved: Radiographic X-ray Machine

Date & place of Incident: Not specified

Exposure to Victims: One AEC contract worker received approximately 3500 rem on the end of the right thumb. Exact exposure to both individuals was cited as being a Class "B" skin exposure.

Injury to Victims: Erythema developed on the end of the right thumb of the individual who held his hand near the operating unit. No clinical injury was reported for the 2nd individual involved.

Circumstances: Two AEC contractor employees were exposed accidentally to X-rays while attempting to radiograph a small metal object. During the course of a series of exposures, the unit operated continuously due to an interal short in the device. The short was so located that it caused bypassing of all normal X-ray controls and interlocks.

Part C: ANALYTICAL X-RAY EQUIPMENT INCIDENTS

Incident 1

Equipment Involved: X-ray Spectrographic Unit
Date & place of Incident: 1967, Michigan
Exposure to the Victim: Dosage could not be accurately established but has been calculated and approximated to be as high as 2,000 rem.
Injury to Victim: Severe X-ray burns to parts of the body that were exposed during a cleaning of a sample changer on an X-ray fluorescence spectrographic unit.
Circumstances: The operator of an X-ray spectrographic unit was attempting a routine cleaning of a sample changer on the unit. The operator bypassed two interlocks on the cabinet of the unit to allow operation of the collimator and sample changer mechanism to permit cleaning of the chamber itself. The cover to the X-ray chamber was removed also. During this changing and cleaning period, the X-ray tube was inadvertently energized and this resulted in an exposure to the individual.

Incident 2

Equipment Involved: X-ray Spectrographic Unit
Date & place of Incident: 1967, New Hampshire
Exposure to Victims: Three individuals were exposed to secondary radiation and one individual was exposed to both primary and secondary radiation. One of the victims exposed to the secondary radiation was approximated to have received a dose of 1700 mrem to the trunk and 4000 mrem to the head and eyes. Another individual, although investigators were unable to estimate exact dosage, was believed to have received the same exposure as the individual mentioned above. The third individual, exposed only to secondary radiation, was believed to have received a much lower exposure than the two previously mentioned people. The exact exposure to this individual could not be determined. The exposure to the fourth individual who received both primary and secondary radiation was approximated at 3400 mrem to the trunk, 95 mrem to the head and eyes, and 150 mrem whole body.
Injury to the Victims: The victim most severely effected was the one who was exposed to both the primary and secondary beam. This exposure resulted in first degree burns to two fingers of the worker. The remaining three workers showed no apparent clinical manifestations of injury. No further radiation injury has been reported.
Circumstances: Failure of a beam shielding device because of a broken spring and failure of an interlocking device which should have prevented removal of a sample holder, resulted in the exposure of four individuals to scattered radiation exposure rates varying from 6000 to 45,000 milliroentgens per hour for varying lengths of time over at least a 3 day period. Three individuals were exposed only to scattered radiation; whereas one individual, after placing her fingers in the beam, received exposure to the primary radiation beam. This individual exposed her fingers to the primary beam while attempting to ascertain why a sample holder was not operating as smoothly and as easily as it was designed to.

Incident 3

Equipment Involved: X-ray Diffraction Unit

Date & place of Incident: Date unknown, Idaho

Exposure to Victim: Victim received approximately 30 mR whole body and 6.65 rem to the skin.

Injury to Victim: No clinical manifestation of radiation injury.

Circumstances: A student at a university was attempting a functional changeover from an X-ray diffraction unit to an X-ray spectrographic unit. In the course of changeover and during alignment of the machine, the victim was inadvertently exposed to the primary beam. The duration of exposure was not specified.

Incident 4

Equipment Involved: X-ray Diffraction Unit

Date & place of Incident: 1968, Massachusetts

Exposure to the Victim: According to reading of a film badge, the victim had received a quarterly dose of 2260 mrem of X-radiation, which is in excess of the allowable quarterly limit.

Injury to the Victim: No clinical injury was reported

Circumstances: A new high intensity X-ray tube was installed in the X-ray diffraction unit. The tube replaced an older one and allowed the instrument to be operated at a level of 50 kV and 40 mA. At conclusion of the installation, radiation surveys revealed that in the area of the shutter a radiation level in the range of 5 to 25 mR per hour existed. The equipment was shut down and additional lead shielding was added. A resurvey revealed that the radiation level had been reduced to less than 1 mR per hour and the equipment was then released for use. During the next month, the equipment was operated intermittently and the bulkiness of the lead shield proved to be a hindrance to efficient operation; consequently, a smaller lead shield was designed and installed. Once again, radiation levels were found to be less than 1 mR per hour. However, it was concluded that the incident occurred during the change from the large shield to the smaller one. It appeared quite probable that the equipment was operating for a short period of time before the small shield was permanently fastened to the unit and that some leakage of X-radiation could have occurred.

Incident 5

Equipment Involved: X-ray Fluorescence Unit

Date & place of Incident: 1965, Pennsylvania

Exposure to the Victims: Not specified

Injury to the Victims: Two individuals were exposed to radiation which resulted in burns to the left hand of each individual.

Circumstances: The accident occurred in an industrial facility and involved two men who operated the X-ray fluorescence unit. Ore samples were placed by hand into the machine for analysis. Both men were overexposed when a spring on the interlock fatigued, thus resulting in interlock failure. The interlock was relied upon to deactivate the X-ray tube, there being no routinely used "off" switch. Thus, the workers unknowingly placed their hands directly into the radiation beam each time a specimen was changed. It was estimated that the interlock was broken for several weeks before it was discovered; each worker's hands were exposed to intense soft radiation for an extended time.

Incident 6

Equipment Involved: X-ray diffraction unit

Date & place of Incident: 1968, Georgia

Exposure to the Victim: An individual was exposed to an estimated dose of between 1200 and 12,000 mrem low energy X-ray from the diffraction machine.

Injury to Victim: Medical examination by physician revealed no symptoms of radiation injury.

Circumstances: An operator of the X-ray diffraction unit was approximately two feet away from the port opening when exposed to a rate of approximately 140 rem per hour. The exposure was directed at a chest level near or on a film badge for approximately 30 seconds before the operator noticed the open port. The exposure was due to a port hole cover being left open while the machine was operating at approximately 12 kV and 30 mA.

Incident 7

Equipment involved: X-ray diffraction unit

Date & place of Incident: 1968, Georgia

Exposure to the Victim: The individual was exposed to an estimated dose of 90 rem of low energy X-ray to the chest. The fingers of the individual's hands were possibly exposed to a dose which has been estimated to be as high as 4500 rem low energy X-ray.

Injury to the Victim: Medical Examination by physician revealed no symptoms of radiation injury.

Circumstances: The operator was working on the unit in an attempt to design a safety interlock system for one of the beam ports. He had completely removed one of the port flip shutters while the X-ray tube was de-energized. The operator then stepped out of the room for a short time not expecting anyone to turn on the diffraction unit. However, during this interval, a colleague, unaware of the condition of the X-ray housing, energized the unit without checking the condition of the safety equipment

Upon doing so, the main beam from the X-ray tube, which was completely unshielded, exited the working area around the machine. This unshielded condition had been estimated to have existed for about five minutes before the operator reentered the room and recognized the hazard. The machine was immediately shut down.

Incident 8

Equipment Involved: X-ray Diffraction Unit
Date & place of Incident: Not specified
Exposure to the Victim: Not specified
Injury to the Victim: Individual incurred an X-ray burn which resulted in a manifestation of blebs which appeared on the second, third, and fourth fingers of the left hand. These areas sloughed and the ulcerations took approximately six to eight months to heal.
Circumstances: An operator of an X-ray diffraction unit suffered an X-ray burn while renovating this unit. The unit operated at approximately 55 kV and 40 mA. Although the exact time of exposure was unknown, the burn was believed to have resulted from a single exposure.

Incident 9

Equipment Involved: X-ray spectrographic unit
Date & place of Incident: Not specified
Exposure to the Victim: Not specified
Injury to Victim: The individual incurred X-ray burns on the index, third, and fourth fingers of the left hand. The areas became ulcerated and atrophy was noted in the terminal portion of the third finger. Amputation at the mid portion of the middle finger was carried out.
Circumstances: A summer employee operated a 50 kV 50 mA X-ray spectrometer. Soreness and redness became apparent in the operator's fingers approximately 1 1/2 to 2 months after he began operating the unit. It was his practice to remove the housing of the unit in order to analyze large samples in the unit.

Incident 10

Equipment Involved: X-ray diffraction unit
Date & place of Incident: Not specified
Exposure to the Victim: Not specified
Injury to the Victim: The victim incurred second and third degree burns on the palm of his left hand.
Circumstances: An individual in the course of taking comparative diffraction photographs, operated an X-ray diffraction unit at 35 kV at approximately 15 mA. A series of exposures was repeated several times during the course of an evening for an approximate total length of two to four minutes. The position of his hand was approximately four inches from the target.

Incident 11

Equipment Involved: X-ray spectrographic unit

Date & place of Incident: Not specified

Exposure to the Victim: The dose was estimated to be in the range of 1000 rem to certain areas of the individual's fingers.

Injury to the Victim: X-ray burns to the fingers which resulted in swelling and reddening and subsequent blister appearance.

Circumstances: The X-ray spectrographic unit which was operated by the individual had been modified to accept samples which were to be analyzed. They were not compatible in size and shape with the sample insertion part of the machine. The sample insertion mechanism, with its protective cover, was therefore removed and temporary lead shielding had been provided as a modification to the unit. As a result, the machine was operated with the interlock being bypassed. The exposure occurred when the researcher removed the temporary shielding assuming that the X-ray spectrograph had been turned off. He reached into the machine and changed the materials to be tested. This resulted in a brief exposure of his fingers to the low energy high intensity output of the primary beam.

Incident 12

Equipment Involved: X-ray spectrographic unit

Date & place of Incident: Not specified

Exposure to the Victim: An employee received an estimated radiation dose of approximately 80,000 rem to an area of his right hand. The thumb, index, and middle fingers received the majority of this radiation exposure.

Injury to the Victim: An employee received an estimated radiation dose of approximately 80,000 rem to an area of his right hand. The thumb, index, and middle fingers received the majority of this radiation exposure.

Injury to the Victim: Not specified

Circumstances: A chemist, who used the X-ray spectrometer for analyzing certain samples, during the course of operation of this machine noticed that moisture on the sample drawer appeared to be originating from inside of the sample chamber. He then wrapped tissue around the index and middle fingers of his right hand and inserted the tissue into the chamber to try to dry the inside of the chamber. During this procedure it is believed that the chemist incurred the radiation exposure.

Incident 13

Equipment Involved: X-ray diffraction unit

Date & place of Incident: Not specified

Exposure to the Victim: No specified

Injury to the Victim: A radiation burn to the distal section of the left little finger.

Circumstances: The day before the exposure, a physicist ran a small sliver of brass into his finger. He extracted it himself and treated the wound. The next day he placed the same finger in the beam of the diffraction apparatus and used a small fluoroscopic screen to see if any brass had remained in it. The radiation burn resulted.

Incident 14

Equipment Involved: X-ray diffraction unit

Date & place of Incident: Not specified

Exposure to the Victim: Not specified

Injury to the Victim: Radiation burn was incurred by a woman on the right, little finger which resulted in a blister and subsequent small scar formation.

Circumstances: The wife of a research worker visited a laboratory during an open house function with the staff. An X-ray diffraction unit was demonstrated by using the woman's little finger of her right hand. Thus, the individual had the small finger exposed to the low energy, high intensity radiation of the primary beam.

Incident 15

Equipment Involved: X-ray diffraction unit

Date & place of Incident: Not specified

Exposure to the Victim: Not specified

Injury to the Victim: A chemist suffered a radiation burn which resulted in the blistering of the left, little finger and subsequent scar tissue formation.

Circumstances: The chemist, eleven days previous to manifestation of the injury, had placed the little finger of his left hand in the beam of the X-ray diffraction unit to demonstrate the bone formation on a fluoroscopic screen. The X-ray diffraction unit was believed to have been operated at approximately 40 kVp, 20 mA without a filter or collimating device. The exposure was estimated to have occurred at a distance of approximately 10 cm from the target of the tube and was estimated to have lasted anywhere between one to thirty seconds.

Incident 16

Equipment Involved: X-ray Thickness Gauge

Date & place of Incident: 1962, 1965, Indiana

Exposure to the Victims: Not specified

Injury to Victims: One electronic repairman exhibited severe inflammatory reaction on his hands, which was diagnosed as acute radiodermititis. A second electronic repairman received a skin reaction on the left index finger, which was diagnosed as radiodermititis. An investigation indicated that there was probably a number of exposures to the primary rays of the X-ray gauge over an extended period of time. The primary rays were extremely collimated.

Incident 17

Equipment Involved: X-ray fluorescence unit.

Date & place of Incident: Sometime during the 1950s, Indiana

Exposure to the Victims: Not specified

Injury to Victim: A laboratory technician was severely burned by X-rays from the X-ray fluorescence unit and lost some of his fingers.

Circumstances: A laboratory technician, while cleaning a sample chamber of an X-ray fluorescence unit, thinking that the unit was shut off was accidentally exposed to X-rays. The unit was thought to have been shut off since the water pressure governing the water cooled X-ray tube had dropped thereby presumably shutting off the X-ray unit.

Incident 18

Equipment Involved: X-ray fluorescence unit.
Date & place of Incident: 1959, Indiana
Exposure to the Victims: Not specified

Injury to Victim: A technician received severe X-ray burns, which resulted in swelling and blistering. He received four skin grafts and eventually had to have about a quarter of an inch of one his fingers removed by amputation.

Circumstances: During routine analysis of a sample cell done with the X-ray fluorescence unit, the sample cell ruptured allowing a portion of the material to leak onto the window of the X-ray tube. The unit was disassembled without the chemist or technician noting that the X-ray unit was still on. The technician cleaned the window of the X-ray unit and was thereby exposed to X-radiation.

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